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EDDY CURRENT PROBE PERFORMANCE REQUIREMENTS

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The result of the work reported here was the development of a procurement specification for single-coil, absolute eddy current probes (shielded and nonshielded) which are used by the USAF with the Hocking UH-B (or equivalent) instruments for inspection of aluminum airframe structures. The specification was necessary because the USAF currently has no adequate means for assuring the quality of eddy current probe performance. The specification establishes minimum performance requirements and associated test methods for determining performance. It also establishes a standard nomenclature for the salient features of probes and a standard probe numbering system that allows the basic characteristics of the probes to be identified on the probe in a uniform manner. A simplified field test procedure for these probes which incorporates a subset of the tests in the specification was also developed.

To establish performance requirements for the specification, the major parameters determining probe performance were defined. Acceptance limits for these parameters were guided by measurements from 30 shielded and 30 nonshielded probes. The probes were obtained from USAF inventory at numerous

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1. INTRODUCTION

Single-coil, absolute eddy current probes (shielded and nonshielded) are used extensively by the U.S. Air Force (USAF) for inspection of aluminum airframe structures. While these probes can successfully perform airframe examinations, the USAF has long recognized it has a problem with consistency of probe characteristics. The major contributor to these variations has been a lack of a specific specification for probe performance. The results are that probes provided to the USAF may not only be unable to perform adequate examinations, but also may not even function at all.

In previous work it has been established that large variations exist in the performance of probes of this type (1). In addition, probes are manufactured in a variety of configurations, yet documentation is often minimal or nonexistent; and part numbers may offer little useful information or may not even be shown on the probes. Unacceptable variations in probe performance and the use of probes with unknown characteristics can affect the reliability and uniformity of inspections at field and depot levels. Therefore, the USAF needed a probe procurement specification and associated test procedures to verify that the specifications were met.

The objectives of the project were to develop (1) a procurement specification and (2) a simple field test procedure for single-coil, absolute eddy current probes. The procurement specification would be used for new probes and would incorporate reasonable minimum criteria for probe performance to eliminate probes with poor performance, yet not reject a high percentage of probes. It would also contain requirements for probe documentation and quality assurance of certain physical characteristics. The field test procedure would contain simplified performance tests to be applied in the field. In addition, the proposed MIL STD XXX, "Eddy Current Probe Performance Characterization," was evaluated with respect to the probe performance requirements.

2. SUMMARY

Project Results: The result of the work reported here was the development of a procurement specification for single-coil, absolute eddy current probes (shielded and nonshielded) which are used by the USAF with the Hocking UH-B (or equivalent) instruments for inspection of aluminum airframe structures. The specification was necessary because the USAF currently has no adequate means for assuring the quality of eddy current probe performance. The specification establishes minimum performance requirements and associated test methods for determining performance. It also establishes a standard nomenclature for the salient features of probes and a standard probe numbering system that allows the basic characteristics of the probes to be identified on the probe in a uniform manner. A simplified field test procedure for these probes which incorporates a subset of the tests in the specification was also developed.

Work Effort: To establish performance requirements for the specification, the major parameters determining probe performance were first defined. Analysis of probe usage led to selection of the following parameters: edge effect, probe impedance, adequate flaw response, noise from liftoff and tilt, and effects of both liftoff and tilt on flaw response.

Selection of acceptance limits for these parameters was guided by measurements from 30 shielded and 30 nonshielded probes. The probes were obtained from USAF inventory at numerous Air Force bases and were representative of probes in current use. Probe impedance measurements were made using an impedance analyzer. The remaining parameters were measured using a Hocking UH-B eddy current instrument, an Air Force general purpose eddy current standard, and two fatigue crack specimens. The Hocking was selected by the USAF for this project based on planned widespread use of the instrument.

It was recognized that setting the acceptance limits to accept only probes having near-ideal performance would be desirable, but this would reject a large number of probes built with current technology and would result in greatly increased probe cost. Therefore, the acceptance limits were set to

reject probes with poor performance and not reject a high percentage of probes with typical performance. The limits were based on a statistical analysis of the data.

The eddy current probes were also subjected to the tests described in MIL STD XXX, which has been proposed as a means to test probes for low sensitivity and poor workmanship. The results showed that the MIL STD XXX tests were not a good indicator of the flaw response obtained with the Hocking UH-B eddy current instrument; possible reasons for this are discussed in the report.

Recommendations: It is recommended that the procurement specification be tested on additional probes in USAF inventory and on incoming probes. The specification should then be used on a trial basis by probe manufacturers for probes delivered to the USAF. After any required revisions are made, the specification should be placed in routine use. Ultimately, a program should be undertaken to provide a generalized performance specification for additional types of probes and eddy current instruments used by the USAF. In addition, a program should be undertaken to determine probe design and manufacturing methods which will consistently produce probes having desired performance characteristics.

Report Contents: Section 3 of this report is an overview of the principles of operation of eddy current probes and the Hocking UH-B instrument. Section 4 describes the experimental setup, the measurements which were made, and the way in which the data were reduced to obtain the parameters of interest. Section 5 describes the experimental results, the acceptance criteria for the procurement specification, the MIL STD XXX tests, highlights of the procurement specification (the specification is in Appendix E), and highlights of the field test procedure (the procedure is in Appendix F). Sections 6 and 7 give the conclusions and recommendations.

3. PRINCIPLES OF OPERATION OF EDDY CURRENT PROBES AND HOCKING UH-B INSTRUMENT

3.1 Probes

One of the most common uses of eddy current testing in the USAF is inspection of aircraft structures made of metals such as aluminum. Eddy current probes for this application usually contain a single coil designed to operate at a frequency of approximately 200 kHz. Typical probes are shown in Figure 3-1. They are most often used by the USAF with meter-type instruments such as the Hocking UH-B. For detection of small surface flaws, coil diameters are usually about 0.3 inch in diameter or smaller; and the coils are typically wound on ferrite cores to increase sensitivity. The coil often is placed inside a cylindrical shield made of materials such as ferrite, steel, or Mumetal, which tend to increase sensitivity by concentrating the eddy current flow in the test piece in a smaller region. Shielding also allows the probe to be used closer to edges and other geometric features without adverse influence on flaw detectability.

The principles of eddy current testing and the electrical impedance characteristics of probes are well documented in the literature (2,3,4) and only a brief overview is presented here. The test coil in an eddy current probe may be represented electrically by the impedance, Z, given by

$$Z = X_L^2 + R^2 \ .* \qquad (1)$$

The inductive reactance, X_L, is represented by

$$X_L = 2\pi f L \qquad (2)$$

where f is the frequency of the applied voltage and L is the coil inductance. R is the ohmic resistance of the coil.

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*The impedance is also affected by capacitive reactance, which is not included in the equation because it is usually negligible at the frequencies of interest (approximately 200 kHz).

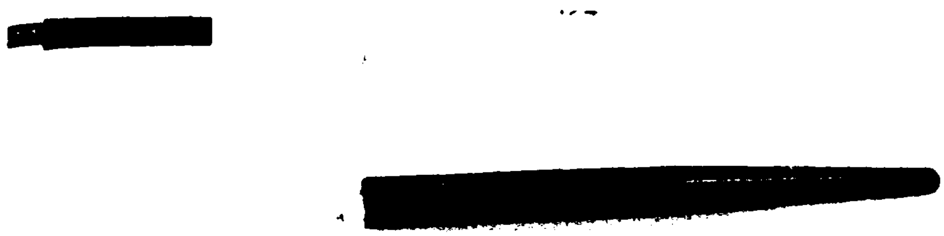


Figure 3-1. Typical single-coil, absolute eddy current probes for inspection of aluminum structures.

When an alternating voltage is applied to the coil, the voltage across the resistance and the reactance are out of phase by 90 degrees. Therefore, the impedance components due to the resistance and reactance are also out of phase by 90 degrees. These components are typically represented on an impedance plane as shown in Figure 3-2. The inductive reactance is plotted on the vertical axis; and the resistance, on the horizontal.

The absolute impedance of the probe in air is shown by P_1 in Figure 3-2. When the probe is placed on a test object, the coil is inductively coupled to the object; and the eddy currents induced in the object cause a change in the values of X_L and R. When the probe is moved from air to an aluminum test object, the impedance moves along the liftoff line (LO in the figure) to a point represented by P_2 in the figure. If the probe is then scanned over a crack, the impedance changes along the line designated by C in the figure. The impedance change caused by liftoff is in a different direction from that caused by a crack.

The initial impedance of the probe as well as the degree of impedance change caused by a test object are influenced by many factors. These include:

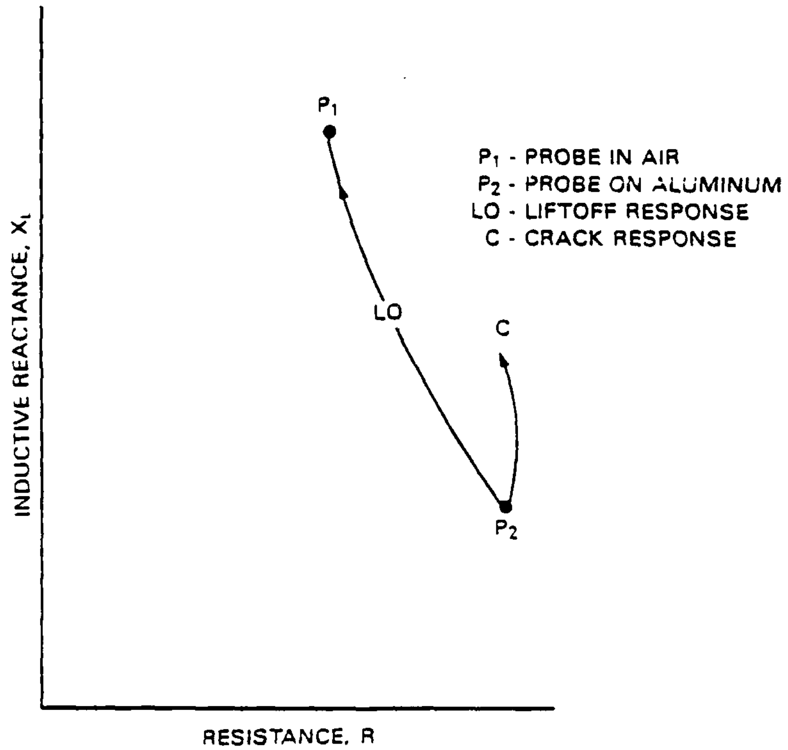


Figure 3-2. Impedance plane plot of eddy current probe response to various conditions.

(1) Probe parameters such as size, shape, number of turns on the coil, type and configuration of core and shielding material, and distance of the coil from the test object (liftoff);

(2) Instrument parameters such as operating frequency; and

(3) Test object parameters such as electrical conductivity, magnetic permeability (not significant for aluminum), and geometry of the test object.

3.2 Hocking UH-B Instrument

The Hocking UH-B is a meter-type eddy current instrument which processes the eddy current probe impedance changes to obtain a meter deflection. In order to minimize the meter deflections (noise) caused by liftoff variations,

the instrument has the capability of being "trained" with a given probe to compensate for liftoff-related impedance changes. Most impedance plane instruments accomplish this by allowing the display to be adjusted so that the impedance component measured is perpendicular to the liftoff direction on the impedance plane. The Hocking instrument utilizes a somewhat different approach based on monitoring the change in oscillator frequency caused by liftoff-induced changes in the inductance of the probe. The amount of frequency shift is used to generate a control voltage, which compensates the oscillator amplitude (and therefore the meter) for liftoff-induced changes in probe resistance. An explanation of the approach was taken from Sections 4-12 through 4-18 of the Hocking manual and is given in Appendix A.

Although the Hocking instrument is normally set to 200 kHz for the type of probes of interest in this report, the actual frequency at which the instrument oscillates depends on the inductance of the probe coil. If the probe impedance is different from the nominal value required by the instrument, the frequency may be higher or lower than 200 kHz.

4. EXPERIMENTAL MEASUREMENTS

4.1 Probes

During the project, 30 shielded and 30 nonshielded probes were tested. These probes, obtained from numerous USAF bases, were representative of probes in routine use for flaw detection in aluminum aircraft structures. Each probe was arbitrarily assigned an identification number for tracking during the experimental evaluations. Probe coil diameters were limited to approximately 0.3 inch or less (the most commonly used sizes for small flaw detection). Coil sizes were measured from radiographs which were made for each probe. There is generally little relationship between the size of the probe body and the coil size. Probes with both flat and rounded tips were included. Table 4-1 shows the probe identification numbers, coil diameters, type of probe (shielded or nonshielded), the ratio of the coil diameter to tip diameter, and tip type (flat or rounded). The coil diameter is the O.D. of the coil for nonshielded probes and the O.D. of the shield for shielded probes.

4.2 Test Blocks

Probe evaluations were conducted on a USAF eddy current test block (P/N 7947479-10, NSN 6635-01-092-5129) containing four EDM slots and on two additional specimens containing existing laboratory-grown fatigue cracks. The slots and crack dimensions are shown in Table 4-2. Both the test block and crack specimens were made of 7075 T6 aluminum.

4.3 Hocking UH-B Measurements

4.3.1 Data Acquisition

The probe evaluations were performed using a Hocking UH-B eddy current instrument calibrated by the factory immediately prior to the evaluations. If the probe did not have a permanently attached cable, connection to the UH-B was made with a 5-foot long RG-174U coaxial cable. The UH-B is a

TABLE 4-1. Probe Physical Characteristics and Assigned Numbers

Shielded Probe No.	Coil Dia. (in.)	Tip Dia. (in.)	Ratio of Coil to Tip Dia.	Tip Type*	Non-shielded Probe No.	Coil Dia. (in.)	Tip Dia. (in.)	Ratio of Coil to Tip Dia.	Tip Type
1	0.1	0.125	0.80	R	3	0.115	0.25	0.46	R
2	0.075	0.125	0.60	R	4	0.11	0.25	0.44	R
6	0.07	0.125	0.56	R	9	0.085	0.125	0.68	R
7	0.065	0.125	0.52	R	11	0.09	0.125	0.72	R
20	0.075	0.125	0.60	R	15	0.12	0.15	0.80	R
21	0.08	0.125	0.64	R	18	0.105	0.25	0.42	R
27	0.07	0.1875	0.37	R	22	NA	0.25	0.25	F
33	0.075	0.1875	0.40	R	25	0.09	0.25	0.36	R
36	0.085	0.2	0.43	R	26	0.175	0.3125	0.56	F
39	0.09	0.159	0.57	F	28	0.11	0.25	0.44	R
43	0.065	0.125	0.52	R	29	0.11	0.125	0.88	F
57	0.08	0.125	0.64	R	32	0.105	0.25	0.42	R
58	0.07	0.125	0.56	R	38	0.09	0.125	0.72	R
59	0.07	0.125	0.56	R	40	0.085	0.125	0.68	R
62	0.09	0.163	0.55	F	41	0.095	0.125	0.76	R
63	0.06	0.125	0.48	R	42	0.185	0.3125	0.59	F
64	0.065	0.125	0.52	R	44	0.175	0.3125	0.56	F
71	0.105	0.1875	0.56	F	46	0.175	0.3125	0.56	F
72	NA	0.1875	NA	R	48	0.17	0.3125	0.54	F
75	0.105	0.125	0.84	R	49	NA	0.312	NA	F
76	0.11	0.125	0.88	R	50	0.105	0.25	0.42	R
77	0.105	0.125	0.84	R	52	0.105	0.25	0.42	R
78	0.105	0.125	0.84	R	53	0.085	0.125	0.68	R
79	0.105	0.125	0.84	R	54	0.105	0.25	0.42	R
80	0.115	0.125	0.92	R	56	0.105	0.25	0.42	R
81	0.1	0.125	0.80	R	67	0.09	0.125	0.72	F
82	0.105	0.125	0.84	R	68	0.085	0.125	0.68	R
83	0.118	0.125	0.94	R	69	0.09	0.125	0.72	R
84	0.15	0.1875	0.80	R	70	0.17	0.3125	0.54	F
85	0.15	0.1875	0.80	R	71	0.105	0.125	0.84	R

*R = Rounded, F = Flat
NA = Not Available

TABLE 4-2. Slot and Crack Dimensions

Flaw No.	Flaw Type	Depth (in.)	Length (in.)
S1	Slot	0.005	1.0
S2	Slot	0.010	1.0
S3	Slot	0.020	1.0
S4	Slot	0.050	1.0
C1	Crack	0.012*	0.05
C2	Crack	0.025*	0.10

*Estimated

meter-type instrument, and the signal output is normally displayed as a meter indication. Instead of recording the meter indication, the analog output of the instrument (which is directly proportional to the meter reading) was recorded with a digitizing oscilloscope and transferred to a computer for analysis. A block diagram of the experimental setup is shown in Figure 4-1.

Probe scanning and tilt were accomplished by a precision, three-axis scanning system driven by stepper motors under computer control, as shown in Figure 4-2. The probes were spring-loaded against the specimen surface using double-cantilever springs to maintain perpendicularity between the probe and the specimen surface regardless of spring deflection.

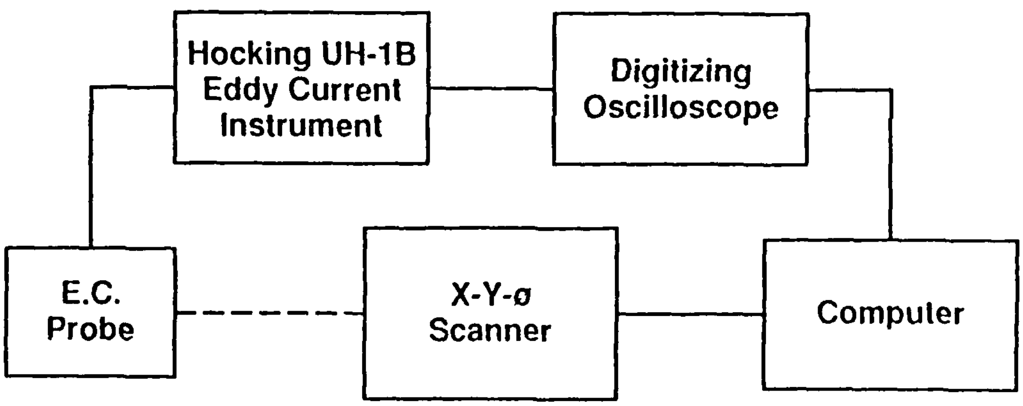


Figure 4-1. Block diagram of experimental setup for measurements with Hocking UH-B.

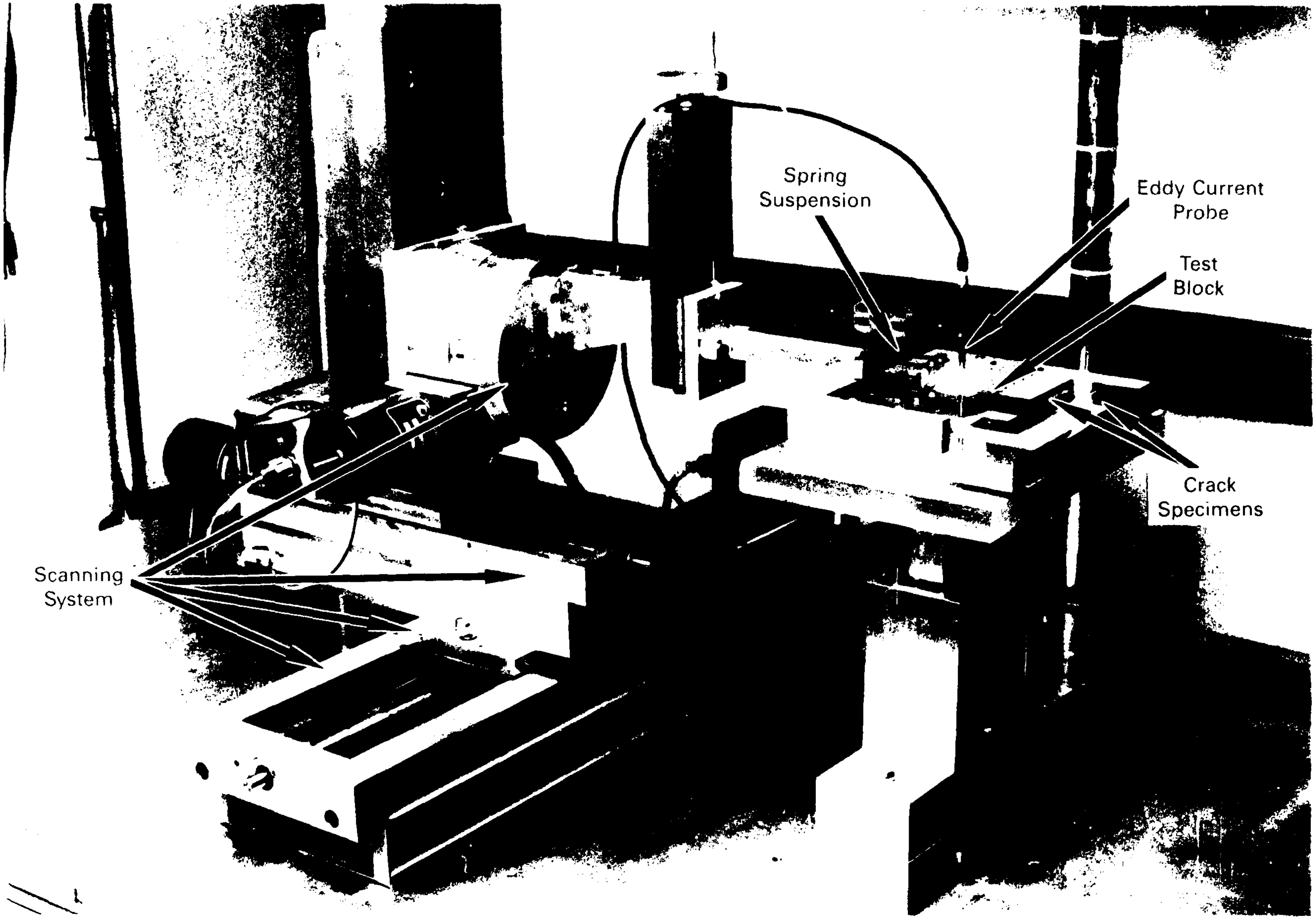


Figure 4-2. Scanning system for eddy current probe measurements.

Three scans over the AF test block and the fatigue crack specimens were made using the following three approaches respectively.

(1) With the probe in contact with and perpendicular to the block surface,

(2) With a 0.006-inch thick plastic spacer between the probe and block surface (probe perpendicular), and

(3) With the probe in contact with the block surface and tilted 10 degrees from the perpendicular (in the direction of the scan).

Prior to the first scan for each probe, the instrument was first adjusted to minimize liftoff effects in the same manner as in a normal setup for flaw detection. This was accomplished using the liftoff "training" procedure in the operating manual for the Hocking UH-B eddy current instrument. A copy of the procedure is in Appendix C. The Hocking UH-B gain was adjusted for each probe to obtain a nominal full-scale response from the largest EDM slot (0.050 inch deep).

The probe scan path for each of the three conditions is shown in Figure 4-3. The probe was first scanned over the center of each slot in the test block. Since the slots were much longer than the probe diameter, it was not necessary to position the probe exactly in the center of the slot length. After scanning the probe over the slots, it was moved onto 0.002- and 0.006-inch thick layers of tape to determine the "noise" caused by liftoff variations. The probe was then moved onto the fatigue crack specimens and scanned over the cracks. Because of the small size of the cracks, the probe could not be positioned precisely with respect to crack length to obtain the maximum crack response in a single scan. Thus, a raster scan was used, as shown in Figure 4-3, in increments spaced 0.005 inch apart until the maximum crack response was obtained. For all scans, the analog signal from the eddy current instrument was digitized every 0.004 inch of probe travel. For scan condition No. 3 (probe tilted), the signal was digitized in 1-degree

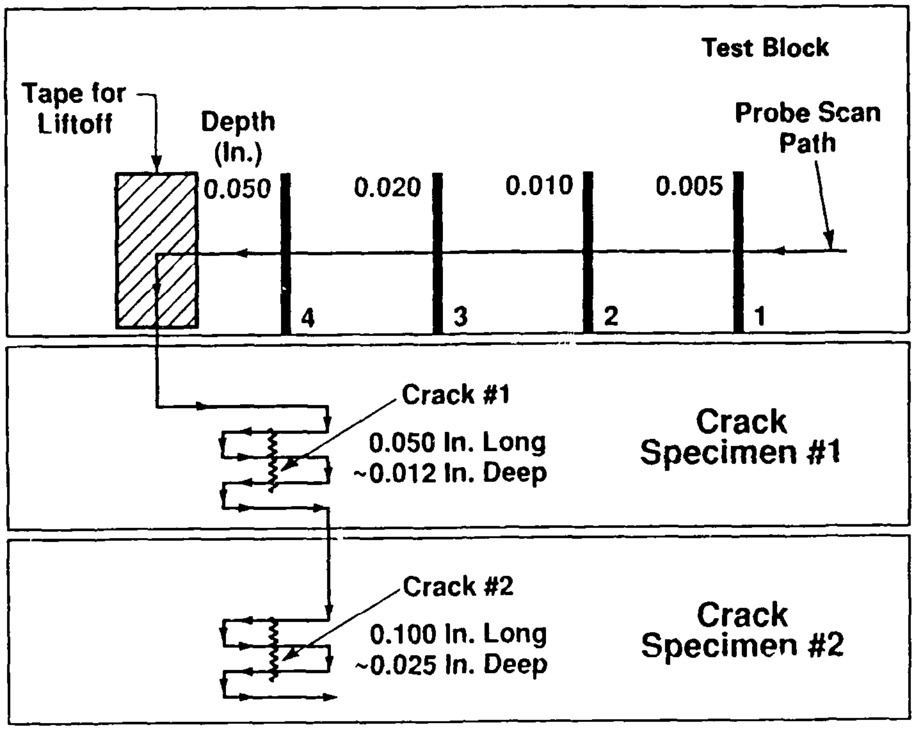


Figure 4-3. Eddy current probe scan path for experimental evaluation.

increments prior to the scan as the probe was being tilted by 10 degrees to determine the "noise" caused by tilting the probe.

4.3.2 Data Reduction

The digitized data were processed by a computer to extract measurements of the parameters shown in Figure 4-4. (Not all parameters were used in the final analysis of the data.) The parameter data were input to a PC Focus database, which was used for ready access to the data for analysis.

Since the experimental data for each of the probes were taken at different gain settings, the data had to be normalized to the equivalent of a common gain setting so that direct comparisons could be made among the data from different probes. Flaw response data taken with several probes as a function of gain setting showed a linear relationship between the eddy current instrument output and the gain setting. A linear normalization, therefore,

1. Slot Response and Width of Slot Response - The peak amplitudes and widths (at 50 percent of maximum) of the signals obtained from slots S1-S4 in the test block with the probe on, and perpendicular to, the block surface.

2. Slot Response and Width of Slot Response with Liftoff - The peak amplitudes and widths (at 50 percent of maximum) of the signals from slots S1-S4 with a 0.006 inch thick spacer between the probe and the block.

3. Slot Response and Width of Slot Response with Tilt - The peak amplitudes and widths (at 50 percent of maximum) of the signals from slots S1-S4 with the probe tilted 10 degrees from perpendicular.

4. Crack Response and Width of Crack Response - The peak amplitudes and widths (at 50 percent of maximum) of the signals from cracks C1 and C2 with the probe on, and perpendicular to, the test block surface.

5. Crack Response and Width of Crack Response with Liftoff - The peak amplitudes and widths (at 50 percent of maximum) of the signals from cracks C1 and C2 with a 0.006-inch thick spacer between the probe and the block.

6. Crack Response and Width of Crack Response with Tilt - The peak amplitudes and widths (at 50 percent of maximum) of the signals from cracks C1 and C2 with the probe tilted 10 degrees from perpendicular.

7. 0.002- and 0.006-inch Liftoff Response - The changes in signal level from lifting the probe off of the test block surface by 0.002 and 0.006 inch with the probe perpendicular to the test block surface.

8. 0.002- and 0.006-inch Liftoff Response with Initial Liftoff - The changes in signal level obtained starting with a 0.006-inch shim between the probe and test block and then lifting the probe off by an additional 0.002 and 0.006 inch.

9. 0.002- and 0.006-inch Liftoff Response with Tilt - The changes in signal level from lifting the probe off of the test block surface by 0.002 and 0.006 inch with the probe tilted 10 degrees from perpendicular.

10. 5-degree and 10-degree Tilt Response - The changes in signal level obtained by starting with the probe perpendicular to the block surface and then tilting it by 5 and 10 degrees.

Figure 4-4. Probe response parameters obtained from Hocking UH-B measurements.

could be applied. The output of the Hocking instrument, however, is not zero at zero gain, and this resulted in an offset in the flaw response versus gain relationship. Projection of the data taken as a function of gain to a zero value showed that a zero signal level would be obtained if the instrument gain could be adjusted to -39. The following equation which incorporates this correction for the offset in gain was used to normalize the data for all probes to a common gain setting of 1000.

$$\text{Normalized Amplitude} = \text{Amplitude} \times \frac{1000 + 39}{\text{Gain} + 39} \qquad (3)$$

4.4 Impedance Measurements

Probe impedance measurements were made with the probe in air using a Hewlett Packard 4194A impedance analyzer. If the probe did not have a permanently attached cable, connection to the analyzer was made with a 5-foot, RG-174U coaxial cable. The impedance measurements were made over a frequency range of 100 Hz to 1.5 MHz, and the digitized data were transferred to a computer for storage and analysis. A computer program was used to extract the parameters shown in Figure 4-5.

1. Inductive Reactance (200 kHz)
2. Resistance (100 Hz and 200 kHz)
3. Impedance (200 kHz)
4. Inductance (200 kHz)
5. Resonant Frequency (Frequency where inductive and capacitive reactances are equal)

Figure 4-5. Probe impedance measurement parameters.

4.5 MIL STD XXX Measurements

Probe impedance measurements in air and on aluminum and titanium blocks were made according to the procedure in MIL STD XXX, Section 5 (Appendix B), using a Hewlett Packard 4194A impedance analyzer at a frequency of 200 kHz. The measurements were made using 7075-T6 aluminum and Titanium 6-4 test blocks measuring 1.4 by 0.75 by 0.75 inch. The test blocks had an EDM-finished surface as specified in the MIL STD. Probe positioning was accomplished using the scanning system described in Section 4.3.1. The data were stored in the database.

5. RESULTS AND DISCUSSION

5.1 Probe Performance Parameters

Major factors limiting flaw detectability with hand-held, absolute (single-coil) eddy current probes are associated with (1) probe impedance, (2) sensitivity to flaws, (3) liftoff, (4) tilt, and (5) edge effects. The probe must have an impedance that is properly matched to the instrument. The probe also must produce a sufficient change in impedance when passed over a flaw so that the eddy current instrument provides an adequate flaw signal and the electronic noise from the instrument does not limit flaw detectability. If these conditions are met, then the primary limiting factors are associated with liftoff and tilt. For probes used close to edges or other significant variations in part geometry, the sensitivity to the edge or part geometry can also be a factor.

When scanning with a probe during inspections, liftoff variations occur because of such factors as variations in the thickness of paint on the part. It is also difficult for the probe axis to be maintained perpendicular to the part surface when performing a manual inspection; the probe is often tilted so that it is at a smaller angle than 90 degrees to the part surface. Liftoff and tilt cause similar problems: (1) fluctuations (noise) in the signal from the eddy current instrument and (2) reduction in flaw signal amplitude.

The noise signals produced by variations in liftoff and tilt can mask flaw signals and reduce the detectability of flaws. The reduction in flaw signal amplitude caused by liftoff and tilt can be detrimental because the eddy current instrument is often adjusted to obtain a given response to a flaw in a nonpainted test block. The inspection, however, may be performed on a painted surface or with the probe tilted. In either case, the flaw response obtained during an inspection may be smaller than expected based on the test block signal.

The absolute magnitude of the probe liftoff and tilt effects is not of primary importance; the factor that limits flaw detectability is the magnitude

of the liftoff or tilt effect compared to the signal obtained from a flaw. For example, the liftoff noise can be large as long as the flaw signal is significantly larger so that the noise does not mask the flaw signal. Therefore, the liftoff and tilt effects may be expressed as ratios with the liftoff or tilt measurement divided by the flaw signal. This normalizes the measurements for all probes so that they can be compared directly.

When a probe is scanned toward an edge or other significant change in part geometry, interfering signals from the edge or geometry change can be severe and mask flaw signals. Shielded probes are typically used for these applications, since the shielding reduces the radial extent of the eddy currents and confines them to a region close to the probe. Edge effect, therefore, is usually of concern only for shielded probes. Although an investigation of the edge response of probes was beyond the scope of this program, a limited investigation was conducted. Edge effect was not measured in the experimental evaluations, but the width of the flaw signal was measured and should be an indicator of the edge effect. For example, if the radial extent of the eddy currents from a probe were large, the probe would produce an edge effect a relatively large distance from an edge, and the probe would also have a wide flaw response. The opposite would be true for a probe confining the eddy currents to a small region.

5.2 Probe Performance Measurements

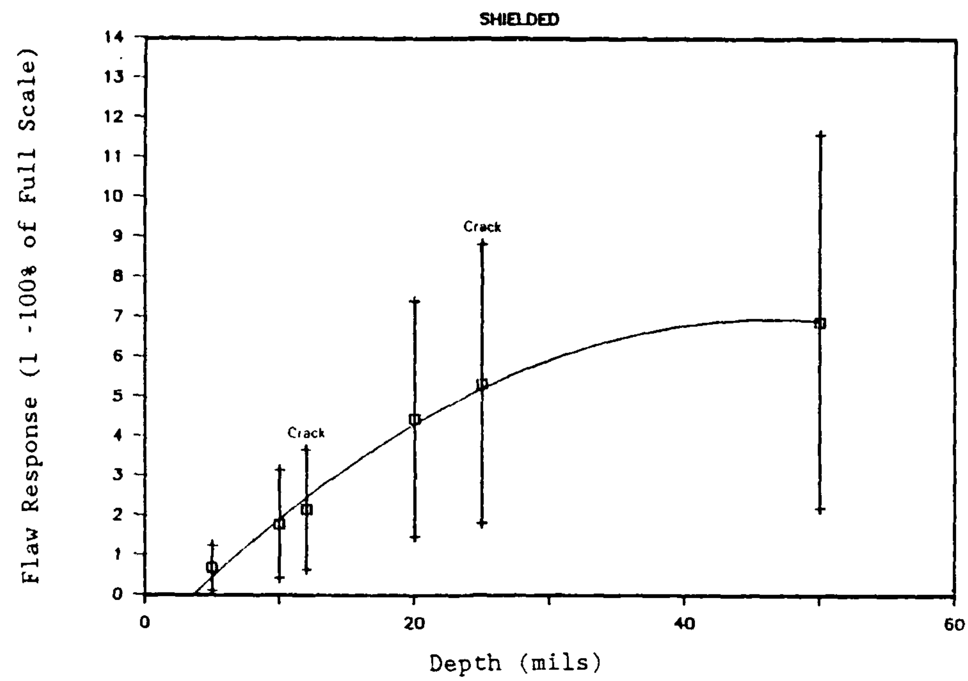
The measured values of parameters described in Section 4.3.2 are shown in Tables D-1 through D-10 in Appendix D for each individual probe. The performance parameters of primary interest (as described above in Section 5.1) were extracted from the experimental measurements and are summarized for all probes and flaws in Section 5.2.1. This analysis gives an overview of the trends in the data and also provides useful information for selecting a type of probe for a particular inspection; e.g. the data show that shielded probes are more affected by some of the parameters than are the nonshielded probes. Following the overview of the data in Section 5.2.1, the determination of acceptance criteria is discussed in Section 5.2.2.

5.2.1 Flaw Response

The flaw response is an indicator that the probe will provide adequate sensitivity to detect a flaw. The flaw response data for the shielded and nonshielded probes are summarized in Figure 5-1 and are shown individually in Tables D-1 and D-2 in Appendix D. The flaw response (normalized to a gain of 1000 for each probe) is plotted on the vertical axis in Figure 5-1; the square represents the mean value for all 30 probes and the + symbols at the ends of the vertical lines represent the mean value ± two standard deviations. (For data having a normal or Gaussian distribution, the lengths of the vertical lines represent values from approximately 95 percent of the probes. Although not all of the data were precisely represented by a normal distribution, the standard deviation still is an indicator of the variation in the data for the probes tested.) The flaw response data are plotted as a function of flaw depth for the four EDM slots and two fatigue cracks. The curved line is a fit to the mean values of the crack and slot data for the shielded probes and to the slot data only for the nonshielded probes.

The mean flaw response values for the shielded probes increase monotonically with flaw depth from a value of 0.66 X full-scale meter deflection (FSMD) for the 0.010-inch deep flaw to a value of 6.9 X FSMD for the 0.050-inch deep flaw. The curve fits the data well for both the slots and the cracks, indicating that the response obtained from a slot would be approximately the same as a fatigue crack of the same depth. For the nonshielded probes, the flaw response values increased from a value of 0.48 X FSMD to 10.8 X FSMD for the smallest and largest flaws, respectively.

A curve was fitted only to the nonshielded probe data from the slots; the crack data fall somewhat below the curve, indicating that a smaller signal would be obtained from a crack than from a slot of the same depth. The reason for this behavior is most likely caused by the fact that the radial extent of the eddy currents from a shielded probe is smaller than that from a nonshielded probe. Because the slots are infinitely long with respect to the eddy current patterns for both types of probes, the slots interrupt the entire eddy current pattern. The cracks (which have a finite length with respect to



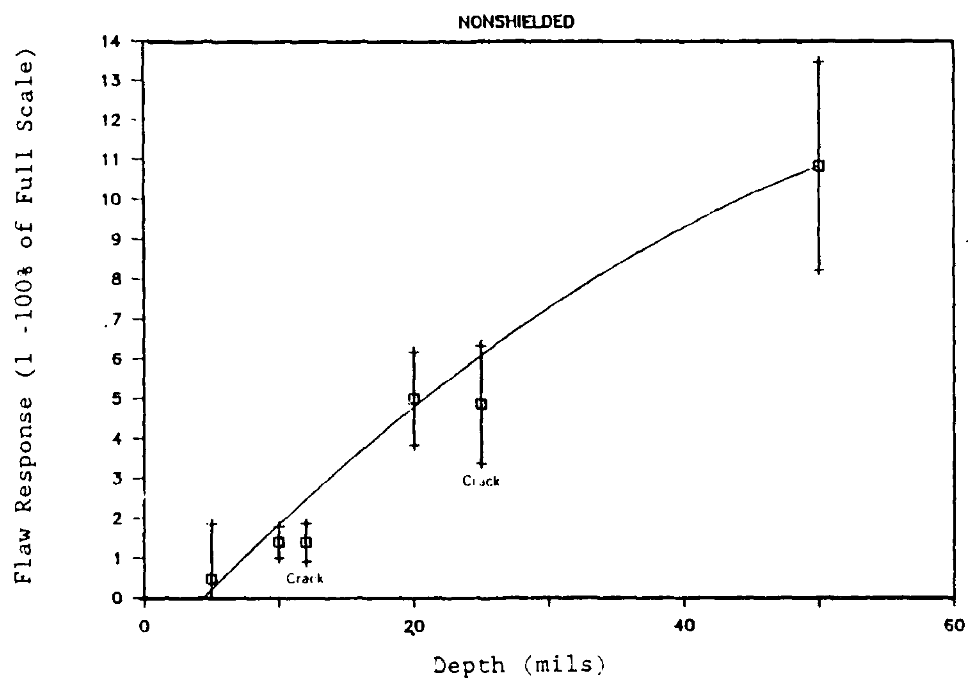


Figure 5-1. Flaw response vs. flaw depth for probes tested. (Boxes represent mean value, and length of vertical lines are mean ± two standard deviations).

the size of the eddy current probes) interrupt a greater percentage of the eddy current pattern from a shielded probe as compared to a nonshielded probe, thus causing the flaw response from a crack to be more like that from a slot.

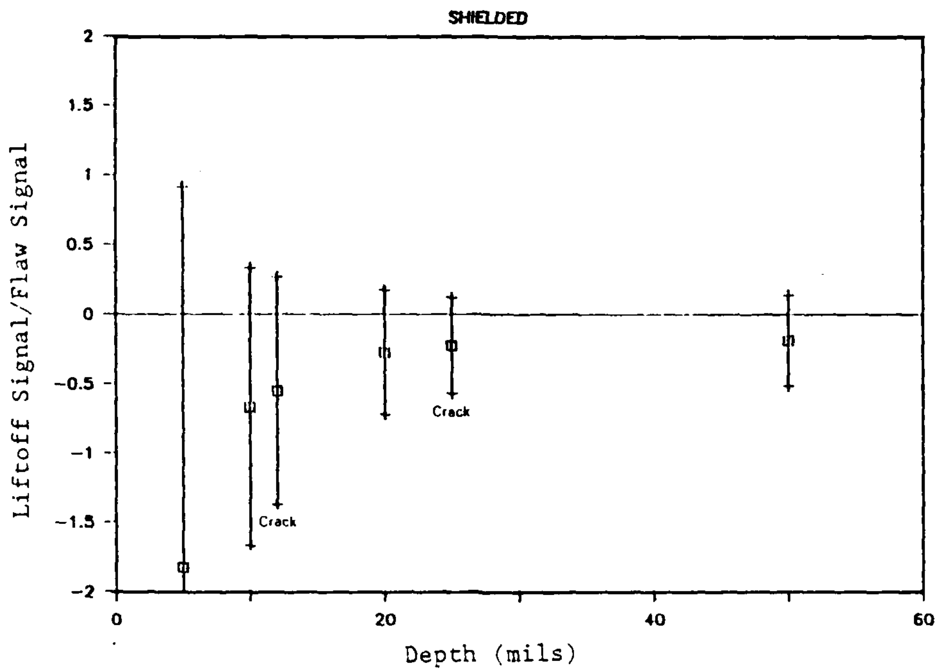
Other interesting trends in the data were that the shielded probes gave a larger flaw response from the smaller flaws than did the non-shielded probes while the opposite result was obtained from the larger flaws. There was also a much larger variation in the responses from the shielded probes than the nonshielded probes, as shown by the lengths of the vertical lines.

5.2.2 Liftoff Noise

The ratio of the liftoff noise signal amplitude to the amplitude of the flaw signal indicates the effectiveness of the probe in detecting flaws where liftoff variations are encountered. An ideal ratio would be zero where no liftoff noise signal is obtained. A value of 1 indicates that the liftoff signal is the same amplitude as the flaw signal; flaw detection would be difficult in this case, since the flaw signals could not be readily distinguished from liftoff signals on the basis of amplitude.

The liftoff noise data for the groups of 30 shielded and 30 nonshielded probes are summarized in Figures 5-2 and 5-3 for 0.006- and 0.002-inch liftoffs, respectively; individual values are shown in Tables D-11 and D-12 in Appendix D. The vertical axis represents the value of the liftoff noise signal divided by the flaw-signal amplitude; a positive liftoff noise value represents an upscale meter deflection from the liftoff variation, and a negative value indicates a downscale deflection.

The experimental data for the 0.006-inch liftoff variation (Figure 5-2) have mean values of -1 and -1.8 for the 0.005-inch flaw for the nonshielded and shielded probes respectively. The mean values decrease (in absolute value) to -0.05 and -0.19 for the 0.050-inch deep flaw. The data for the 0.002-inch liftoff variation (Figure 5-3) have mean values of 0.93 and



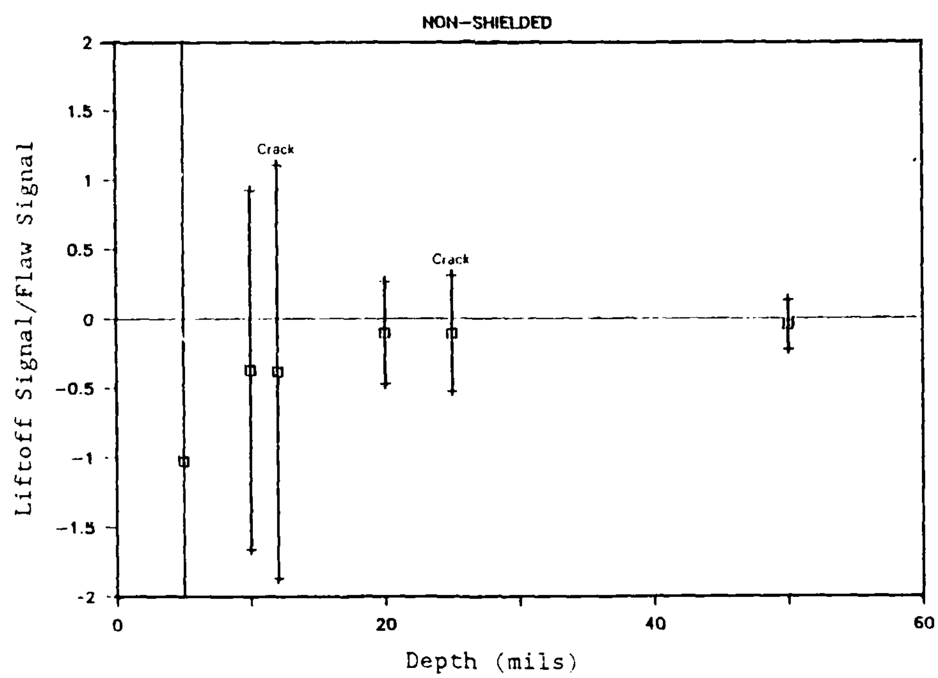
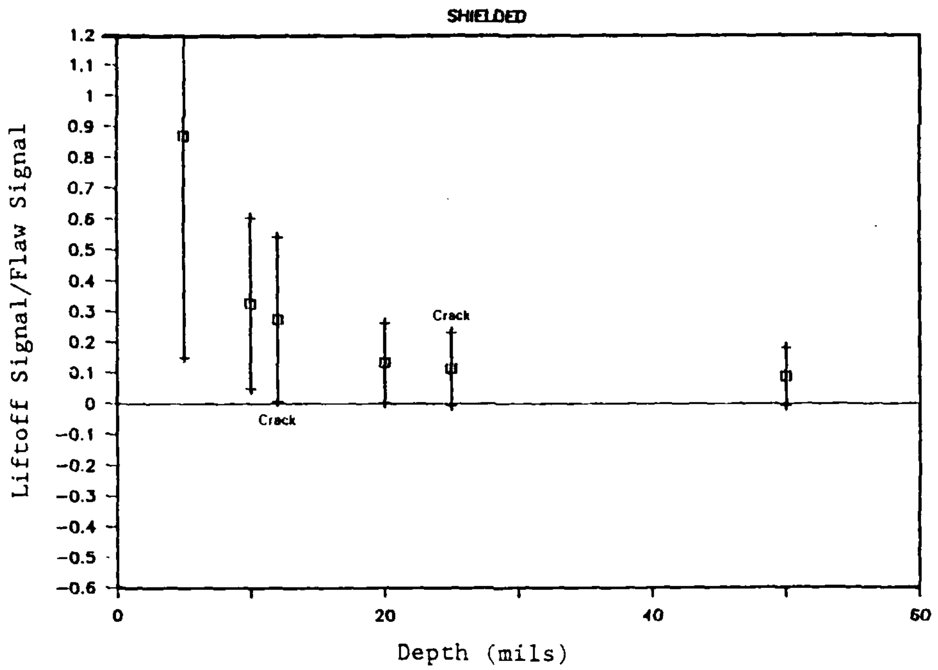


Figure 5-2. Liftoff noise ratio for 0.006-inch liftoff versus flaw depth for probes tested. (Boxes represent mean value, and length of vertical lines are mean ± two standard deviations).



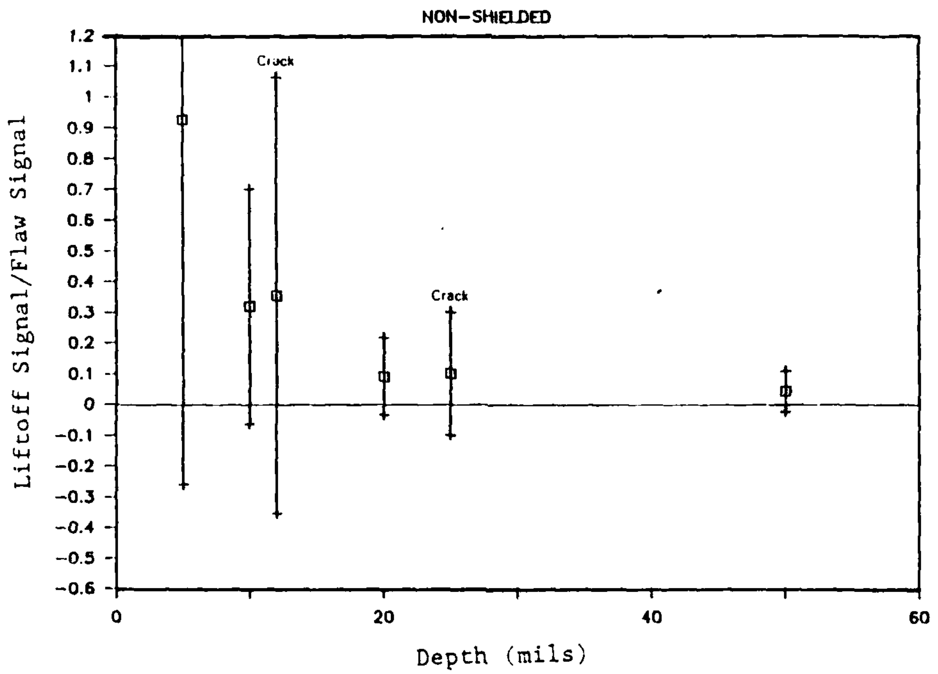


Figure 5-3. Liftoff noise for 0.002-inch liftoff versus flaw depth for probes tested. (Boxes represent mean value, and length of vertical lines are mean ± two standard deviations).

0.87 for the 0.005-inch flaw for the nonshielded and shielded probes respectively. The mean values decrease to 0.044 and 0.087 for the 0.050-inch deep flaw.

The data (absolute value) for the 0.006-inch liftoff variation show that the nonshielded probes have consistently smaller values for all flaws than do the shielded probes. The 0.002-inch liftoff data show no consistent trend for the two types of probes, since the nonshielded probes have smaller values for some flaws and larger values for other flaws when compared to the shielded probes. The mean values for the shielded and nonshielded probes, however, are very similar for the 0.002-inch liftoff. Overall, the nonshielded probes would be more effective for detection of flaws in the presence of liftoff variations on the order of 0.006 inch, but would perform approximately the same as the shielded probes for smaller liftoff variations on the order of 0.002 inch.

5.2.3 Tilt Noise

The ratio of the tilt noise signal amplitude to the amplitude of the flaw signal indicates the effectiveness of the probe in detecting flaws where the probe angle (with respect to the part surface) varies during scanning. As with the liftoff noise, the ideal value would be zero. A value of 1 would indicate that the tilt signal is the same amplitude as the flaw signal, thus tending to mask the flaw indication.

The tilt noise data for the shielded and nonshielded probes are summarized in Figure 5-4, and individual values are given in Tables D-11 and D-12 in Appendix D. The vertical axis is the ratio of the tilt noise signal to the flaw signal; these data are plotted as a function of flaw depth for the slots and cracks. The tilt data showed that probes with a tip diameter greater than 0.25 inch (nonshielded probe Nos. 26, 42, 44, 46, 48, 49, 70; none of the shielded probes) were severely affected by tilt. Because of the larger size of these probes, it should be possible for an inspector to keep the probe aligned with the part surface without significantly tilting it. For

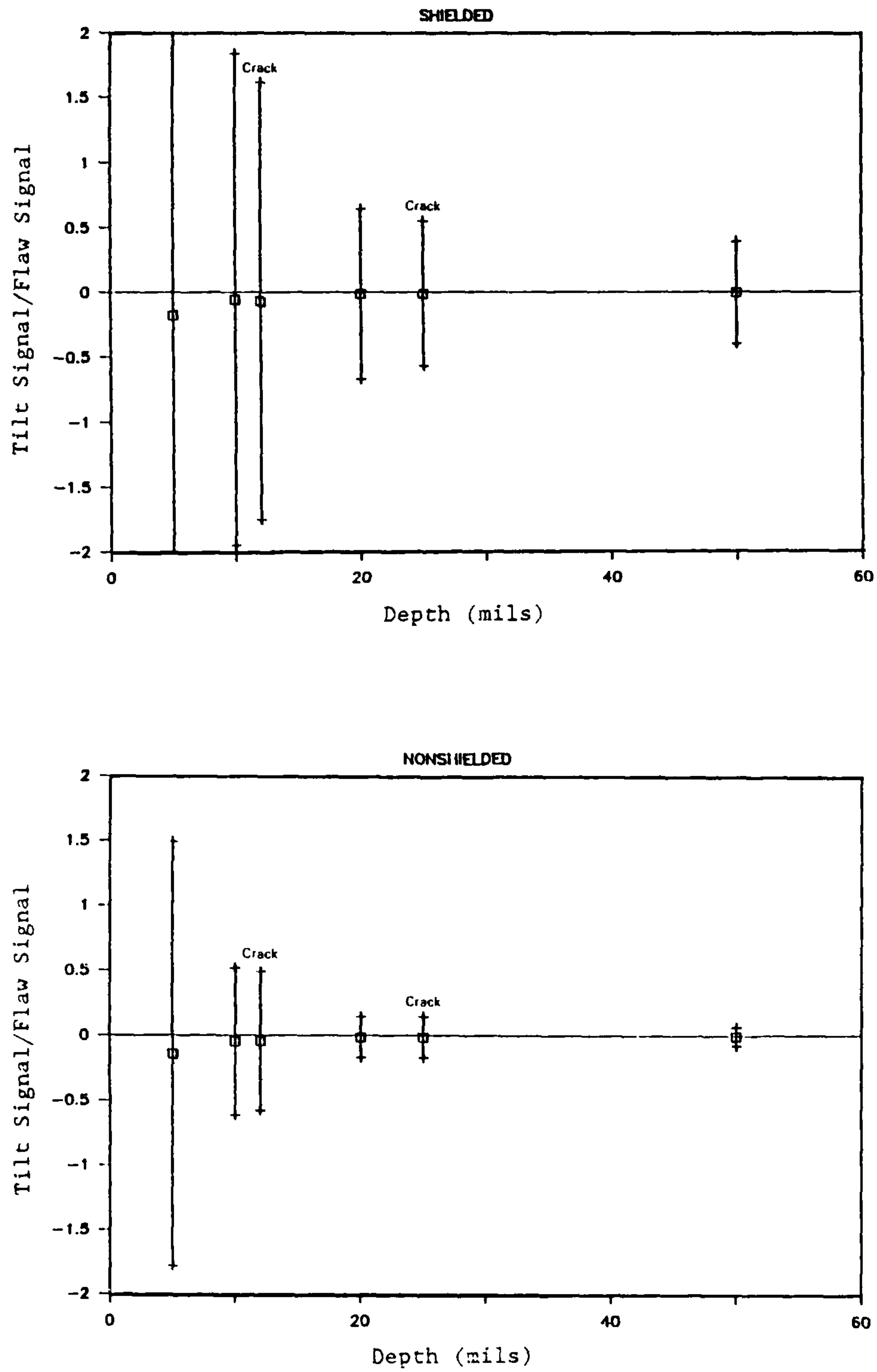


Figure 5-4. Tilt noise for 10-degree tilt versus flaw depth for probes tested. (Boxes represent mean value, and length of vertical lines are mean ± two standard deviations).

this reason, the six nonshielded probes with a tip diameter greater than 0.25 inch were excluded from the data in Figure 5-4.

The mean values for the nonshielded probes range from -0.14 for the 0.005-inch deep slot to -0.007 for the 0.050-inch deep slot. The mean values for the shielded probes range from -0.18 for the 0.005-inch deep slot to -0.004 for the 0.050-inch-deep slot. Overall, the mean values for the nonshielded and shielded probes were approximately the same for probes with tip diameters less than 0.25 inch; the shielded probes, however, showed a much larger range of values, with a standard deviation of three to four times that of the nonshielded probes.

5.2.4 Effect of Liftoff on Flaw Response

The amplitudes of the flaw signals obtained with the probe lifted off 0.006 inch divided by the flaw-signal amplitudes with no liftoff are summarized in Figure 5-5; individual values are shown in Tables D-11 and D-12 in Appendix D. Ideally, this ratio would have a value of 1 where no degradation in signal amplitude occurs when the probe is lifted off and where the same flaw-signal amplitude is obtained with or without liftoff. Values less than 1 indicate that the flaw-signal amplitude has decreased when the probe is lifted off.

The experimental data show that this ratio is not strongly affected by flaw size, although differences exist between the values obtained from slots and cracks. The mean values for the shielded probes range from 0.25 to 0.36 for the slots and from 0.45 to 0.50 for the cracks. The mean values for the nonshielded probes ranged from 0.59 to 0.69 for the slots and from 0.71 to 0.77 for the cracks. The mean values of the flaw signals from the shielded probes are approximately 50 percent of those from the nonshielded probes, indicating that the shielded probes are more strongly affected by liftoff.

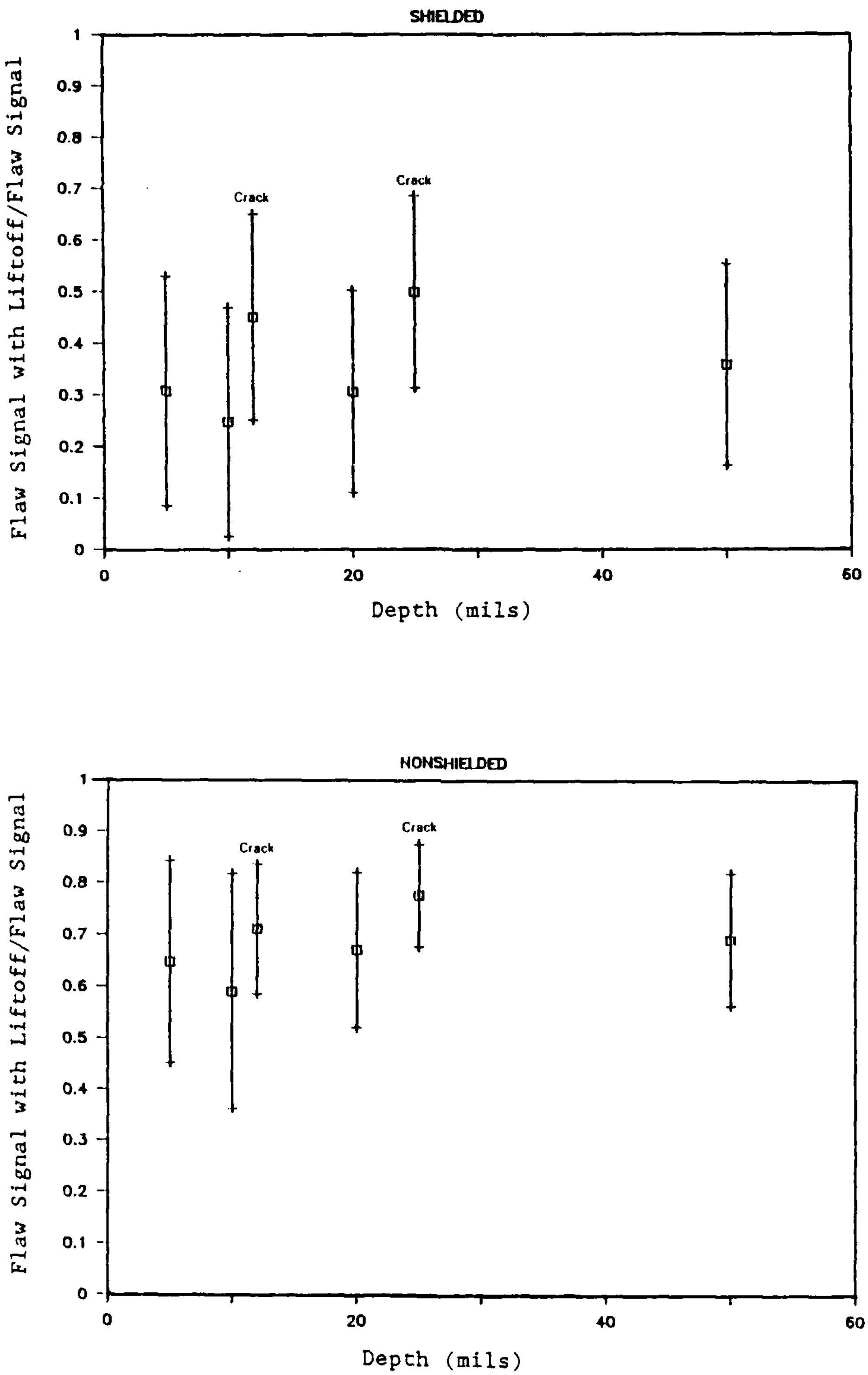


Figure 5-5. Effect of 0.006-inch liftoff on flaw signal for probes tested. (Boxes represent mean value, and length of vertical lines are mean ± two standard deviations).

5.2.5 Effect of Tilt on Flaw Response

The amplitudes of the flaw signals obtained with the probe tilted 10 degrees divided by the flaw-signal amplitude with the probe perpendicular are summarized in Figure 5-6; data for individual probes are shown in Tables D-11 and D-12 in Appendix D. Note that the data shown in the figure are only for probes having tip diameters greater than 0.25 inch (see Section 5.2.3). As with the effect of liftoff, an ideal value for this ratio would be 1 where the same flaw signal amplitude is obtained with or without the probe tilted. Values less than 1 indicate that the flaw signal has decreased when the probe is tilted. In some cases a value slightly greater than 1 can be obtained, thus indicating that the flaw response is larger with the probe tilted.

The data showed that this ratio is not strongly affected by flaw size. The mean values for the shielded probes ranged from 0.58 to 0.77 for all of the flaws. The mean values for the nonshielded probes were somewhat larger with values ranging from 0.75 to 0.91. The shielded probes showed more variation, with the standard deviation approximately a factor of 2 larger than for the nonshielded probes.

5.2.6 Width of Flaw Response

The width of the flaw response was measured as an indicator of the radial extent of the eddy currents and, thus, of the susceptibility of the probe to the presence of edges and other geometric part variations. Because the probe diameters varied, and it was expected that the signal width or edge effect would vary accordingly (5), an attempt was made to establish a simple relationship between the probe diameter and the width of the flaw response. (The probe diameter was the outside diameter of the shield as determined from measurements from radiographs of the probes.) The width of the flaw response was plotted as a function of the probe diameter for each of the probes and the results are shown in Figure 5-7. As shown, no unique relationship was obtained. A more thorough investigation into other factors that may affect

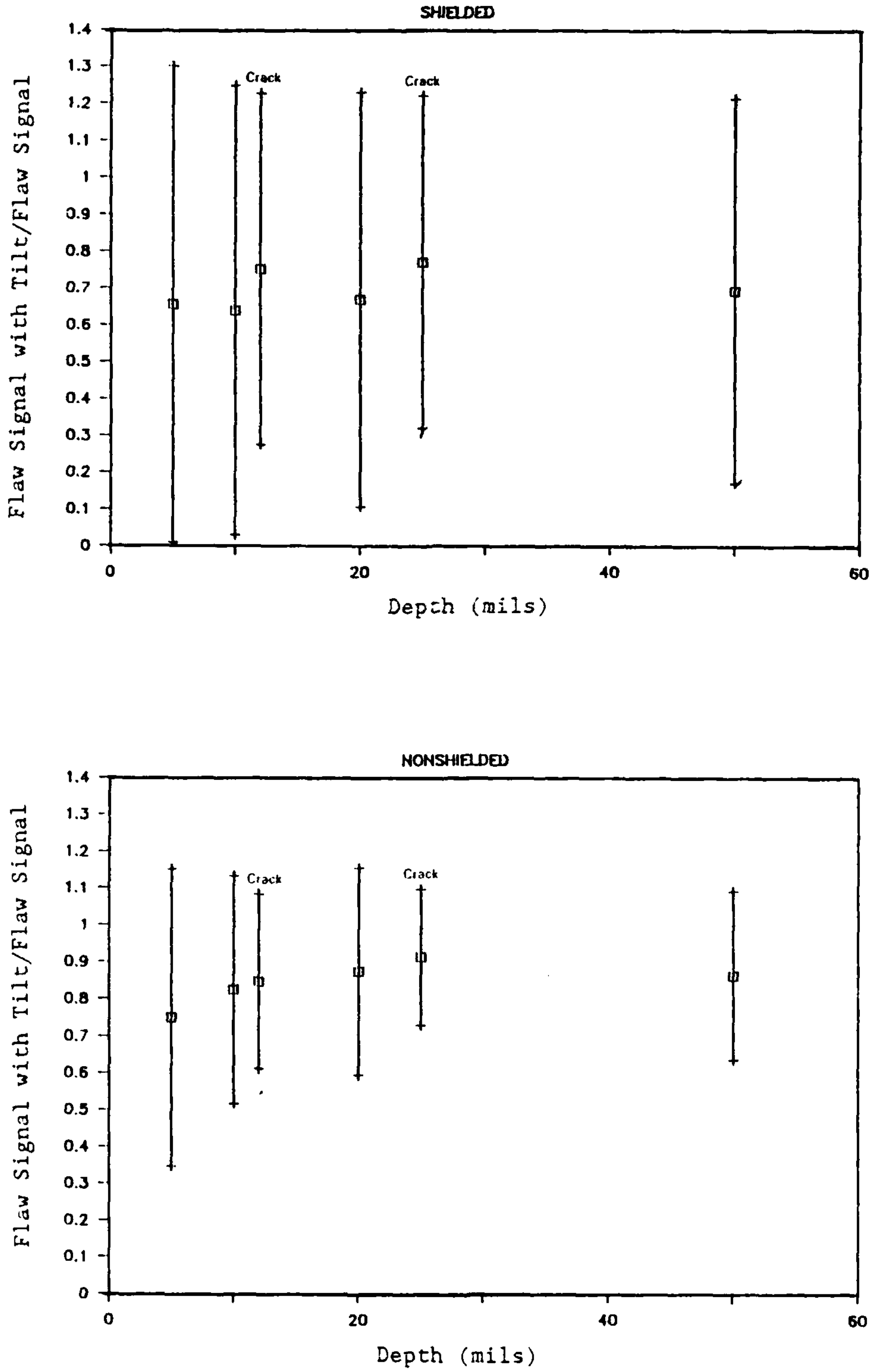


Figure 5-6. Effect of 10-degree probe tilt on flaw signal for probes tested. (Boxes represent mean value, and length of vertical lines are mean ± two standard deviations).

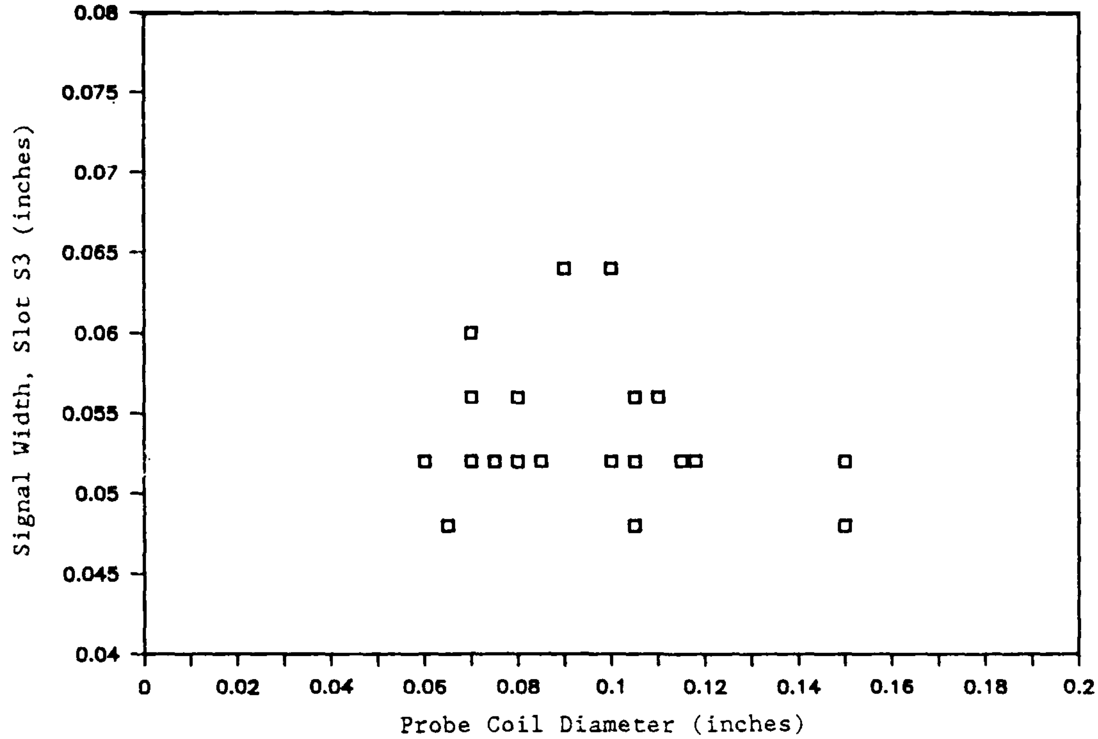


Figure 5-7. Flaw signal width (0.02-inch deep slot) versus coil diameter for shielded probes.

the relationship (e.g., probe design, shielding materials, and liftoff of coil from probe tip) was beyond the scope of the project.

5.2.7 Probe Impedance

The measured probe impedance, inductance, resistance, and resonant frequency values are shown in Tables D-13 and D-14 in Appendix D. The Hocking UH-B instrument is designed for operation at the 200-kHz frequency switch setting with probes having an inductance of 80 to 200 μH and a DC resistance of 2 to 7 ohms as stated in the operating manual. Except for one nonshielded and four shielded probes, all had values within these ranges.

5.3 Acceptance Criteria

Although it would be desirable to set acceptance limits for the procurement specification so that only probes with near-ideal performance would be accepted, this would not be realistic. A very high percentage of probes built

using current technology would not be acceptable. This would result in large numbers of probes being removed from current inventory as well as increased cost of new probes. Therefore, the measurements of probe performance made in this project were used as a guide to determine probe performance so that acceptance criteria could be set to reject probes with poor performance, yet not reject a high percentage of probes with typical performance. A statistical analysis was used for the liftoff and tilt parameters; the statistical analysis was not appropriate for the other parameters, generally because all of the probes met the criteria.

5.3.1 Flaw Response

In order for a probe to have an acceptable flaw response, it was judged that a full scale meter response should be obtainable within the maximum gain adjustment provided by the instrument (up to 1000). Preferably, it should not be necessary to use the maximum gain (a gain setting of 750 or less should be adequate). All of the probes tested would meet this criterion for flaws with a depth of 0.02 inch or greater, since the smallest flaw response (normalized to a gain of 1000) from the 0.02-inch deep slot was 1.84 times full scale. This response would correspond to 1.4 times full scale with a gain setting of 750. Based on this rationale, the acceptance criterion for flaw response was set at obtaining a full scale response with a gain setting no larger than 750.

5.3.2 Liftoff and Tilt Parameters

The acceptance criteria for the liftoff and tilt parameters were guided by a statistical analysis of the data. A probability distribution curve (Gaussian or normal fit) was fitted to the data for each parameter, as shown schematically in Figure 5-8. The horizontal axis represents the value of the measured parameter, and the vertical axis represents the probability that the measurement from a probe will be of a given value. [All of the fitted curves were subjected to a Kolmogorov-Smirnov statistical test to measure how well the curve fits the actual data; the test showed a significance level of ≥0.05 for all of the data which indicates a good fit (6).] The percentage

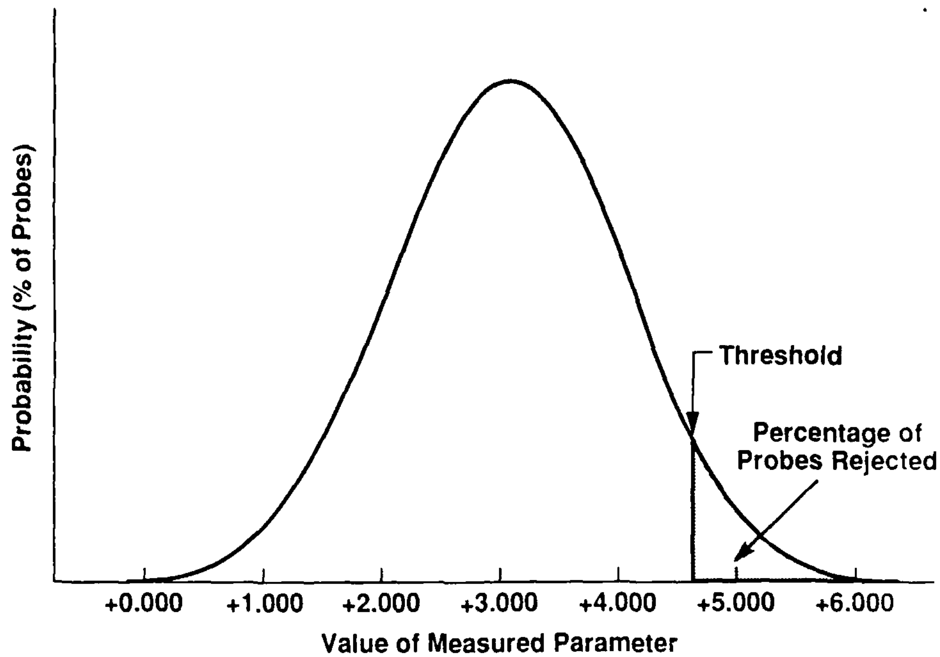


Figure 5-8. Schematic of probability distribution curve showing percentage of probes rejected for values exceeding given acceptance threshold.

of probes with measurements exceeding a certain threshold value can be determined by calculating the area bounded by a vertical line positioned at the desired threshold value and also bounded by the curve to one side of the vertical line, as shown by the shaded area in the figure (7). [If the desired percentage of probes (i.e., the area under the curve) is known, the value at which the threshold is placed can be calculated.]

For the purposes of this analysis, the number of rejected probes was determined for several values of selected thresholds. The thresholds covered a range from a minimum value that would provide good probe performance to a more optimum value that would result in too many probes being rejected.

The acceptance criteria were based on the probe response to slot No. 3 (0.020 inch deep). This slot was chosen because it is a relatively small flaw typically encountered in actual inspections. The liftoff and tilt noise ratios for this flaw were also in a range which would be easily measurable in practice.

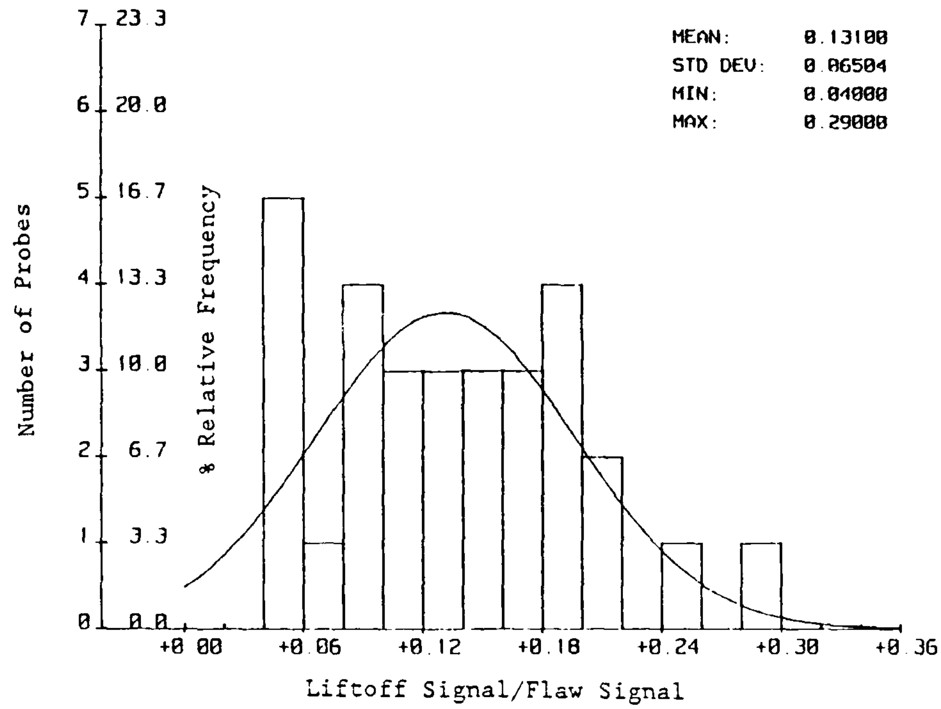
(1) Liftoff Noise

The acceptance criteria were based on the response to a 0.002-inch liftoff variation. Since the relatively large negative values obtained with the 0.006-inch liftoff variation would be more difficult to deal with in a practical probe test because the eddy current instrument meter only has a range of 10 percent of full scale in the negative direction.

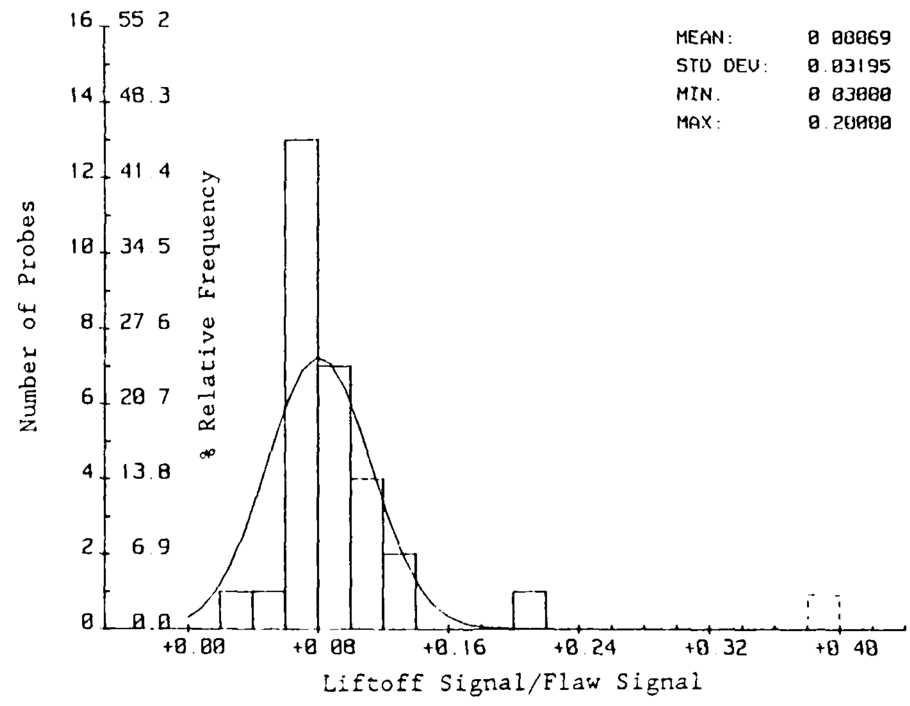
The liftoff-noise probability distributions for the shielded and nonshielded probes for slot No. 3 are show in Figure 5-9. The number of probes is shown on the vertical axis, along with the percent relative frequency which represents the percentage of the total number of probes. The liftoff noise ratio is plotted on the horizontal axis. The width of each box in the histogram represents a liftoff noise ratio value of 0.02. The height of each box shows the number of probes (or percent of probes) having a value in the range shown on the horizontal axis. For example, four shielded probes (or 13.3 percent of the 30 probes) had liftoff ratio values between 0.08 and 0.1, and another four probes had values between 0.18 and 0.2.

Gaussian curves have been fitted to the data; and the mean, standard deviation, minimum data value, and maximum data values are shown in the upper right corner of the plot. For the nonshielded probes, it was necessary to delete the value shown by the box with the dashed lines in order to obtain a curve which fits the data well (according to the normality criteria).

The percentage of rejected probes for thresholds of 0.1, 0.2, and 0.25 (probes with values larger than the thresholds would be rejected) were calculated based on the Gaussian distribution and are shown in Table 5-1 (columns labeled "Distribution"). The percentage of rejected probes based on the actual data in the histogram were also calculated and are shown in the table (columns labeled "Actual Data"). A value of 0.25 was considered to provide the minimum acceptable performance; i.e., the noise signal could be 25 percent of the flaw-signal amplitude. The 0.25 value would reject 3 percent and 0 percent of the shielded and nonshielded probes respectively



(a) Shielded



(b) Nonshielded

Figure 5-9. Liftoff noise probability distributions for 0.002-inch liftoff and 0.02-inch deep slot.

TABLE 5-1. Percentage of Probes Rejected for Various Acceptance Thresholds for Liftoff and Tilt Parameters

Parameter	Threshold	% of Probes Rejected			
		Shielded		Nonshielded	
		Distribution	Actual Data	Distribution	Actual Data
Liftoff Noise	0.1	68	60	27	23
	0.2	14	13	0.01	3
	0.25*	3	3	0	3
Tilt Noise	±0.1	45	50	0.1	4
	±0.2	16	13	0	4
	±0.25	5.3	10	0	4
	+0.25, -0.1*	13	13	0.1	4
Effect of Liftoff on Flaw Signal	0.1	1.8	0	0	0
	0.2*	14	13	0	0
	0.25	29	30	0	0
	0.5	98	90	1	0
Effect of Tilt on Flaw Signal	0.1	2	0	0	0
	0.2*	5	7	0	0
	0.25	7	13	0	0
	0.5	28	23	0.4	4
Total Rejected for All Parameters for Selected Thresholds Shown by *		35	23[1]	0.1	7[1]

*Selected thresholds.
[1]Total not equal to sum of individual values since some probes are rejected by more than one parameter.

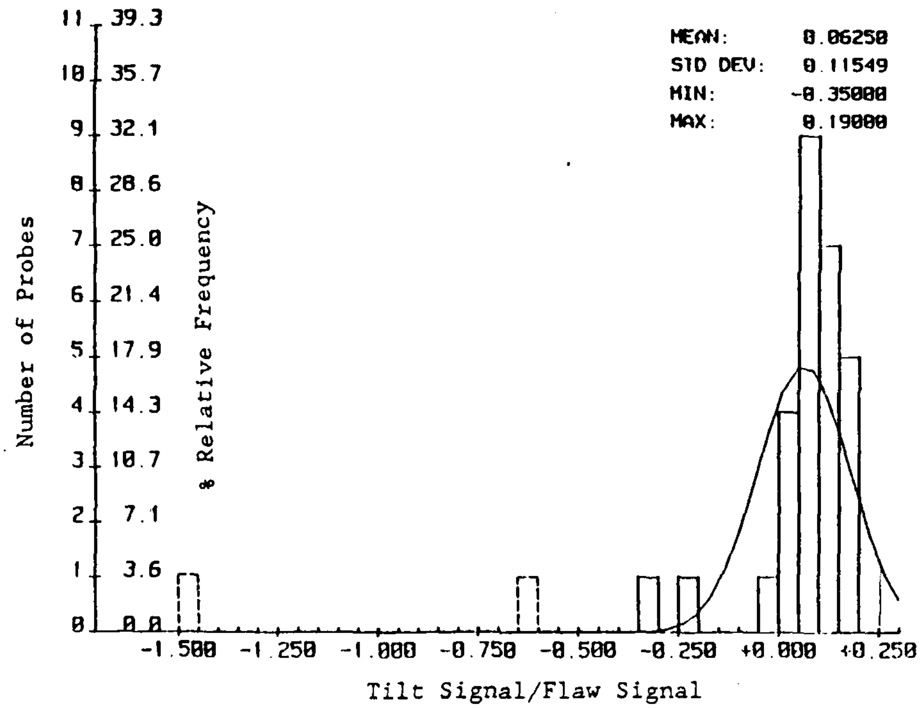
based on the Gaussian distribution. Using a value of 0.1, the noise would be only 10 percent of the flaw-signal amplitude; however, a large percentage of probes would be rejected. A value of 0.1 would reject 68 percent of the shielded probes and 27 percent of the nonshielded probes.

(2) Tilt Noise

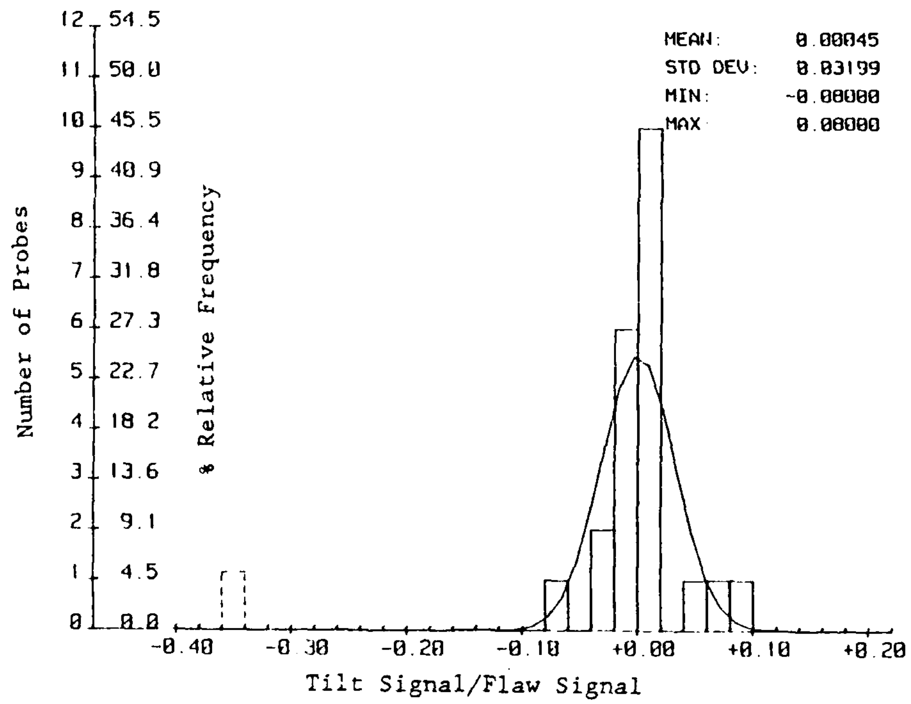
Probes with tip diameters greater than 0.25 inch were excluded from this analysis because they produced excessive tilt values and because probes greater than this size were judged less likely to be tilted, since they are easier to hold in alignment with the part under inspection. This resulted in the exclusion of seven nonshielded probes and no shielded probes. The distributions for the tilt noise are shown in Figure 5-10. The probes represented by the dashed histogram boxes were excluded in order to obtain a good Gaussian fit.

The analysis of the tilt noise data is somewhat more complicated because some of the values are negative. Therefore, both a positive and a negative threshold must be set. The percentage of rejected probes for thresholds of ±0.1, ±0.2, and ±0.25 were calculated and are shown in Table 5-1. A probe having a value greater than the positive threshold or less than the negative threshold would be rejected. For the shielded probes, different percentages for the positive and negative values resulted because the distribution was not centered about zero; the table shows the total from both positive and negative values. As with the liftoff noise, a value of ±0.25 was considered to provide the minimum acceptable probe performance. The number of shielded and nonshielded probes rejected were 5.3 percent and 0 percent respectively for a tilt noise value of ±0.25, and 45 percent and 0.1 percent respectively for a value of ±0.1.

The negative tilt noise values also presented a difficulty in using the thresholds with the Hocking UH-B because the instrument only has a 10 percent of full scale meter deflection in the negative direction. Thus, if the flaw response were set to 100 percent of positive full scale, then it would not be possible to measure a tilt noise response of -0.25 because it would result in a 25 percent negative deflection. Because of this difficulty,



(a) Shielded



(b) Nonshielded

Figure 5-10. Tilt noise probability distributions for 10-degree tilt and 0.02-inch deep slot.

different thresholds would be required for the positive and negative directions. For example, setting the positive threshold at 0.25 and the negative threshold at -0.1 would allow the threshold values to remain on the meter scale. The setting would result in 5 percent of the shielded probes being rejected based on the 0.25 threshold and 8 percent being rejected based on the -0.1 negative threshold for a total of 13 percent. For the nonshielded probes, it would result in 0 percent being rejected from the positive threshold and 0.1 percent being rejected from the negative threshold.

(3) Effect of Liftoff on Flaw Signal

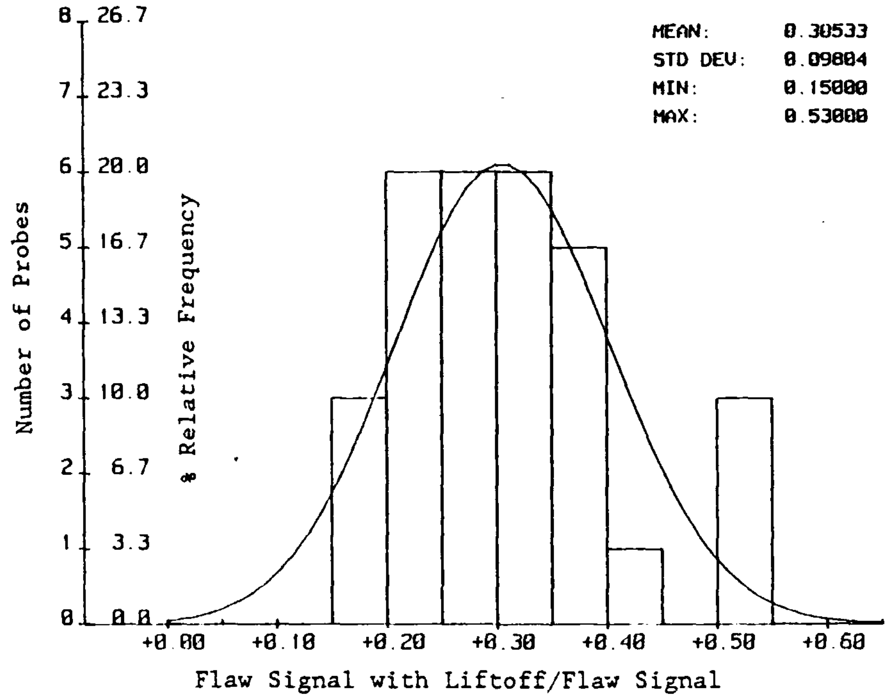
Distributions for the effect of liftoff on the flaw signal are shown in Figure 5-11. Calculations of the number of probes rejected were made for thresholds of 0.1, 0.2, 0.25, and 0.5 and are shown in Table 5-1. Here, the probes rejected are those having values less than the threshold, as a value closer to 1 indicates better probe performance. A value of 0.2 was judged to be the minimum acceptable value and would reject 14 percent and 0 percent of the shielded and nonshielded probes respectively. A 0.2 value would mean that the signal amplitude obtained from the flaw with a probe liftoff of 0.006 inch would be 20 percent of the amplitude obtained without liftoff. While a value of 0.5 would be more desirable, almost all of the shielded probes (98 percent) would then be rejected.

(4) Effect of Tilt on Flaw Signal

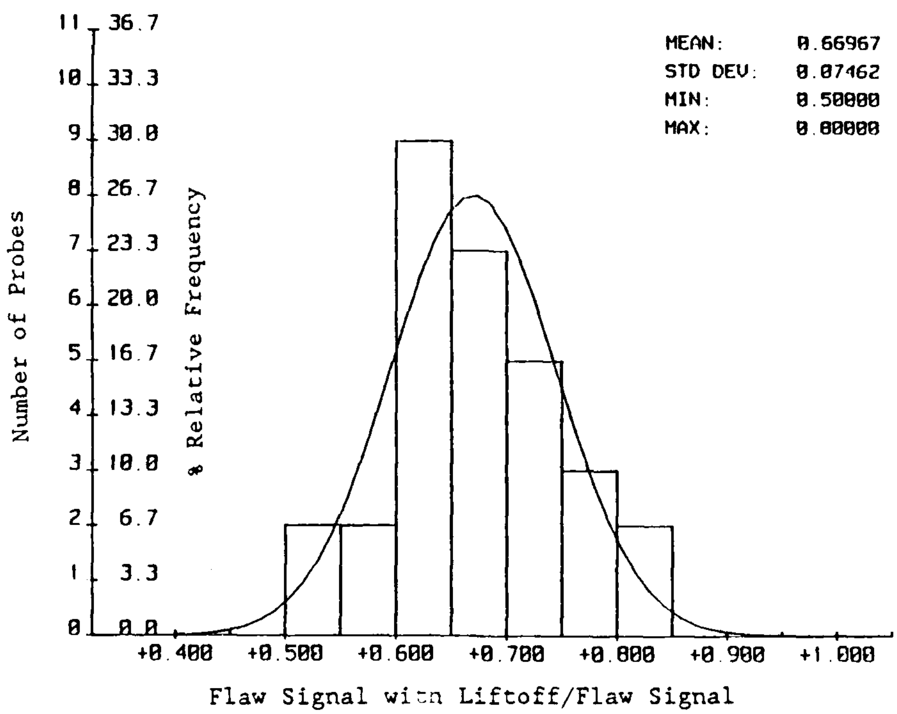
Distributions for the effect of tilt on the flaw signal are shown in Figure 5-12, and calculations for the number of probes rejected are shown in Table 5-1. Again, the probes rejected are those having values less than the threshold. A value of 0.2, judged to be the minimum acceptable value, would reject 5 percent of the shielded and 0 percent of the nonshielded probes respectively.

(5) Summary of Liftoff and Tilt Acceptance Criteria

The selected values for the liftoff and tilt parameters are designated by a "*" in Table 5-1. These values were considered to be the

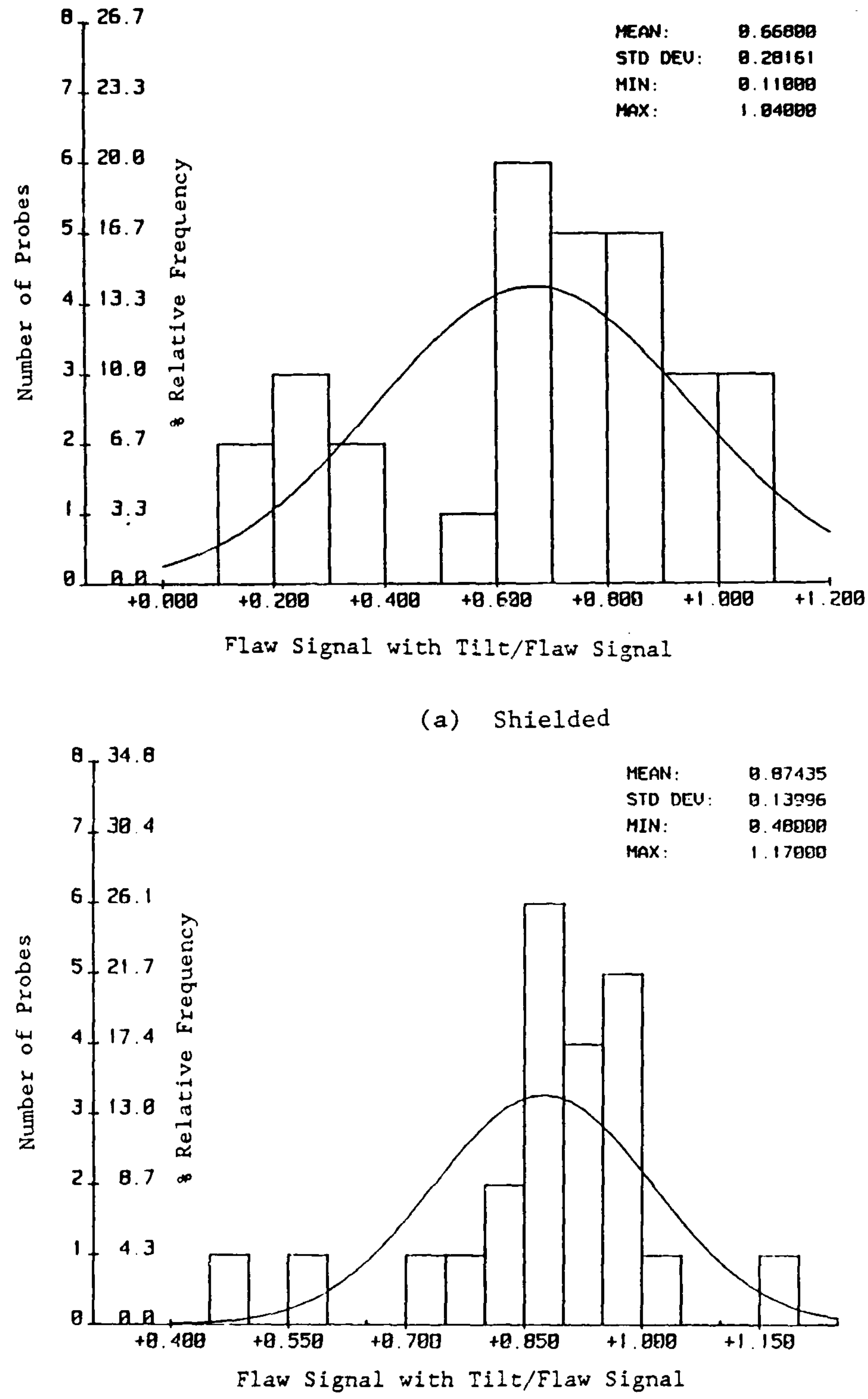


(a) Shielded



(b) Nonshielded

Figure 5-11. Probability distributions for effect of 0.006-inch liftoff on flaw signal.



(a) Shielded

(b) Nonshielded

Figure 5-12. Probability distributions for effect of 10-degree probe tilt on flaw signal.

minimum which would provide acceptable probe performance. The maximum percentage of rejected probes based on these criteria and the Gaussian fit would be equal to the sum of the rejected percentages for all parameters. These values are 35 percent of the shielded probes and 0.1 percent of the nonshielded probes. This is a worst case based on different probes being rejected by each parameter. In some cases, the same probes are rejected by more than one parameter, thus reducing the total rejected. This effect cannot be evaluated using the Gaussian fit; however, it can be illustrated using the actual data shown by the histograms. Adding the percentage of probes rejected for each parameter based on the data gives 36 percent and 0.1 percent for the shielded and nonshielded probes respectively. Accounting for probes rejected by more than one parameter gives 23 percent and 0.1 percent for the shielded and nonshielded probes. It may be expected that the percentages rejected by the Gaussian fit would be reduced by approximately the same amount.

5.3.3 Width of Flaw Response

As discussed in Section 5.2.6, it would not be appropriate to set a fixed width for the flaw response because the probe coil diameters can vary. Unfortunately, a unique relationship was not obtained between the flaw signal width and coil diameter; and it was not possible to pursue a more involved investigation. The data do show that the flaw signal width was always less than the coil diameter. A criterion based on the flaw signal width being equal to or less than the coil diameter appears to be a reasonable choice for rejecting probes that have excessively large eddy current patterns.

5.3.4 Probe Impedance

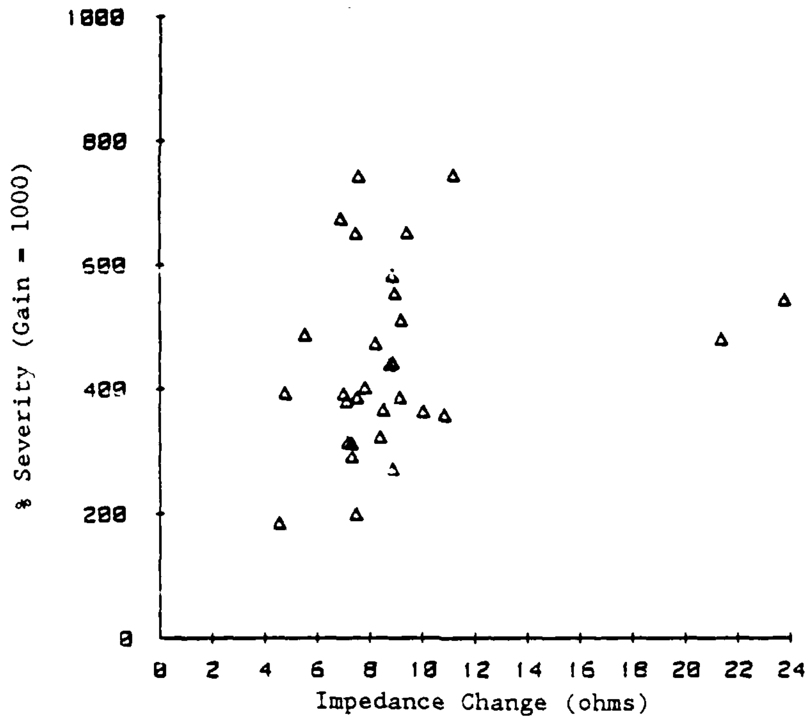
Even though the inductance range of 80 to 200 μH is acceptable for instrument operation, a variation in operating frequency would result from approximately 160 to 260 kHz would result. In order to provide better control over the operating frequency, and subsequently the penetration depth of the eddy current in the part being tested, it is recommended that, for new probes, the probe inductance be controlled within a tighter range than specified by the Hocking manufacturer. An acceptable inductance range of 160 to 110 μH,

which would control the frequency to approximately 180 kHz to 220 kHz, is recommended. The resistance tolerance of 2 to 7 ohms specified by the manufacturer does not affect the frequency and should be satisfactory. These tolerances on inductance and resistance are easy to achieve in probe fabrication. For this reason, the inductance and resistance values were not subjected to a statistical analysis to determine how many typical probes would be rejected.

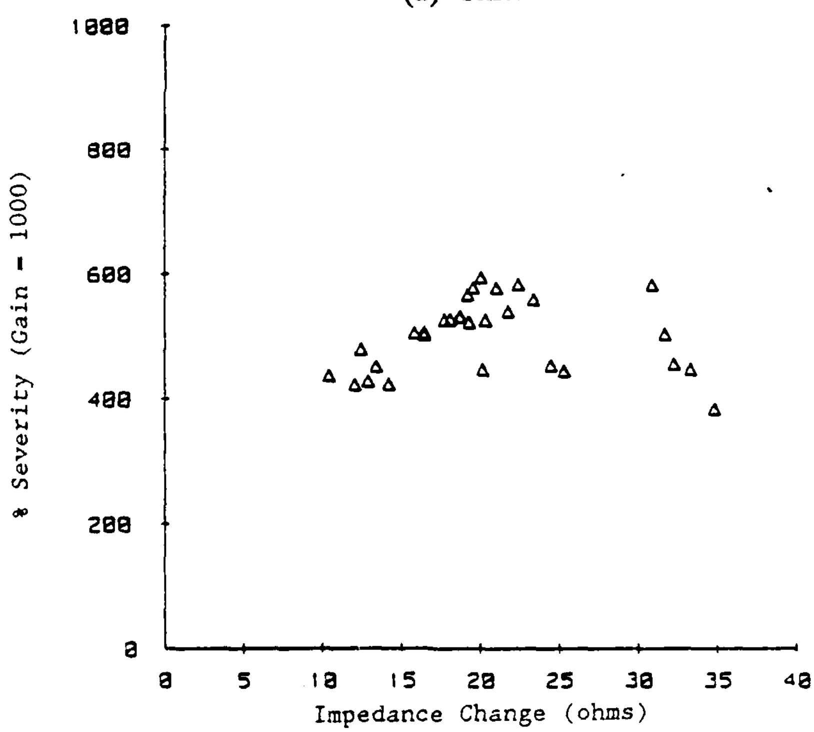
5.4 MIL STD XXX

Experimental data were obtained from the groups of shielded and nonshielded probes according to proposed MIL-STD-XXX (MSX). This procedure involves measuring the probe impedance in air and the change in impedance obtained by placing the probe on an aluminum block and then on a titanium block. The data for individual probes are shown in Tables D-15 and D-16 in Appendix D. The results from this process were compared to the measurements obtained using the same probes with the Hocking UH-B eddy current instrument. Since the MSX test does not involve liftoff or tilt measurements, only the magnitude of the flaw response obtained with the Hocking could be compared to the magnitude of the impedance change obtained by moving the probe from the aluminum to the titanium block. This comparison was made to see if the impedance test were an indicator of how each probe would perform for flaw detection with the eddy current instrument.

The results of the above comparison are shown in Figure 5-13 for the shielded and nonshielded probes respectively. The responses obtained from the 0.020-inch deep slot in the test block for each probe used with the Hocking instrument were plotted versus the aluminum-to-titanium impedance change obtained according to the MSX test. As seen from the data for both the shielded and nonshielded probes, no unique relationship was found between the flaw response using the Hocking and the impedance change obtained by moving the probe from the aluminum to the titanium block. For example, the nonshielded probe with the smallest impedance change (10 ohms) gave approximately the same Hocking response (430 percent severity) as the probe with the second to largest impedance change (35 ohms). Therefore, the aluminum-to-titanium



(a) Shielded



(b) Nonshielded

Figure 5-13. Hocking UH-B response to 0.02-inch deep slot versus aluminum-to-titanium impedance change.

impedance change does not appear to be a good indicator of the flaw response obtained with the Hocking UH-B.

Several reasons could account for the different responses from the impedance measurements and the Hocking. First, the impedance change from the aluminum and titanium blocks is produced by a bulk change in conductivity of the blocks. The impedance change obtained from the slots in the aluminum test block, however, is produced by a localized disturbance in the eddy current flow patterns in the test block. These two conditions could produce quite different results. Second, the impedance measurements were made at a frequency of 200 kHz, the nominal operating frequency of the Hocking instrument. Because of the wide variation in absolute probe impedances, the actual operating frequency of the Hocking varies from probe to probe. Therefore, the impedance change obtained at 200 kHz would be different than that obtained at the actual operating frequency of the Hocking. Third, the way in which the Hocking circuitry processes the probe impedance change to reduce liftoff effects may also produce a response different than that obtained by simply measuring the magnitude of the impedance change as in MSX.

Despite the fact that the MSX tests did not show a good relationship with the Hocking flaw-response measurements, the MSX test may still be effective for rejecting probes of poor quality which simply do not produce a flaw response usable by the eddy current instrument. The effectiveness of MSX for this purpose was difficult to judge from the probes tested because all of the probes passed the MSX test criterion (impedance change = >2 ohms), and all performed well with the Hocking.

5.5 Probe Procurement Specification

A procurement specification was developed and is included in Appendix E. The specification covers single-coil, absolute eddy current probes intended for inspection of aluminum structures with a meter-type instrument such as the Hocking UH-B or equivalent. The specification includes a standard nomenclature for eddy current probes, a probe identification scheme that requires identification of key probe characteristics on the probe body or cable, and

quality control for certain probe construction parameters. Probe tests which incorporate the performance parameters discussed in Section 5.1 and the minimum acceptance criteria described in Section 5.2.2 are included in the specification.

5.6 Field Test Procedure

A simplified field test procedure for eddy current probes, given in Appendix F, can be used by inspectors at the field level to periodically test probes. The procedure is a simplified version of the tests in the procurement specification (Appendix E). The tilt and flaw response width parameters are excluded from the procedure because of the need for precision fixtures which would not be appropriate in the field.

6. CONCLUSIONS

Parameters important for assessing probe performance were determined to be

- Flaw response,
- Liftoff noise,
- Tilt noise,
- Effect of liftoff on the flaw signal,
- Effect of tilt on the flaw signal,
- Edge effect, and
- Probe impedance.

Analysis of measurements from groups of 30 shielded and 30 nonshielded probes showed that reasonable acceptance limits could be set on probe performance without rejecting a large percentage of typical probes. These acceptance limits were incorporated into a draft probe procurement specification. The tests outlined in proposed MIL STD XXX did not show a good correlation with flaw response tests using a typical eddy current instrument. A draft probe procurement specification based on the performance parameters and acceptance limits described above was developed to improve the quality of probes used by the USAF.

7. RECOMMENDATIONS

The probe performance tests described in the draft procurement specification developed in this project should initially be evaluated by USAF personnel on typical incoming probes and probes in inventory to test the specification on a larger number of probes. The specification should then be used on a trial basis by probe manufacturers to check probes delivered to the USAF. Any required revisions should be made, and then the specification should be placed in routine use.

Ultimately, a program should be undertaken to provide a generalized performance specification for additional types of eddy current probes and instruments used by the USAF. In addition, a program should be undertaken to determine probe design and manufacturing methods that will consistently produce probes having desired performance characteristics.

8. REFERENCES

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APPENDIX A

THEORY OF OPERATION OF HOCKING UH-B EDDY CURRENT INSTRUMENT
(FROM TO 33B2-7-11, 28 FEBRUARY 1986, PRELIMINARY)

Section IV

THEORY OF OPERATION

4-1. GENERAL.

4-2. The portable Flaw Detector, Eddy Current is capable of detecting surface-breaking cracks in ferrous and non-ferrous metals having a conductivity range of 1-100% IACS. Three different operating frequencies may be selected to meet specific applications, taking into account metal, shape, accessibility, defect size and position with a variety of probes (not supplied).

4-3. The Flaw Detector is designed to compensate automatically for lift-off effects by a simple "train" procedure. It is quickly "trained" and placed into operation (see Section V). This automatic "lift-off effects" compensation feature reduces operator dependence and the need for experience, skill and ability to achieve identical settings.

4-4. FREQUENCY SETTINGS.

4-5. The Flaw Detector may be set to three different settings:

a. 200KHz - for use as a general purpose instrument. Certain probes may used for both ferrous and non-ferrous applications. The supplied probe (A29-P201) is for both applications.

b. 2MHz - used to find small defects in low conductivity alloys and for use as a general purpose instrument.

c. 6MHz - well-suited to finding very small defects in low conductivity alloys.

4-6. PROBES.

4-7. A wide range of probes is available to cover general and special requirements. Standard types include pencil, shielded probe - straight, shielded probe - right angled, and bolt hole-threaded. The Flaw Detector is supplied with one general purpose probe. See Section 1, List of Items Furnished.

4-8. THEORY OF OPERATION (See Figure 4-1.)

4-9. An oscillator generates continuous oscillations at one of three selected frequencies. The frequency current is conducted through a coaxial cable to a coil in the tip of the probe. When the tip of the probe is placed on the surface of the metal to be tested, eddy currents are induced in the metal. These induced eddy currents produce their own electromagnetic field which oppose the coil field and modify the original oscillations, altering the effective resistance and inductance of the coil in the tip of the probe.

4-10. The effective inductance of the probe is reduced with nonferrous metals because there is now a smaller flux for a given probe current. The effective resistance of the probe has changed because circulating eddy currents dissipate energy. This energy is dissipated in the probe coil and may be described as having increased series resistance. The amplitude of the oscillations is damped by the series resistance increase.

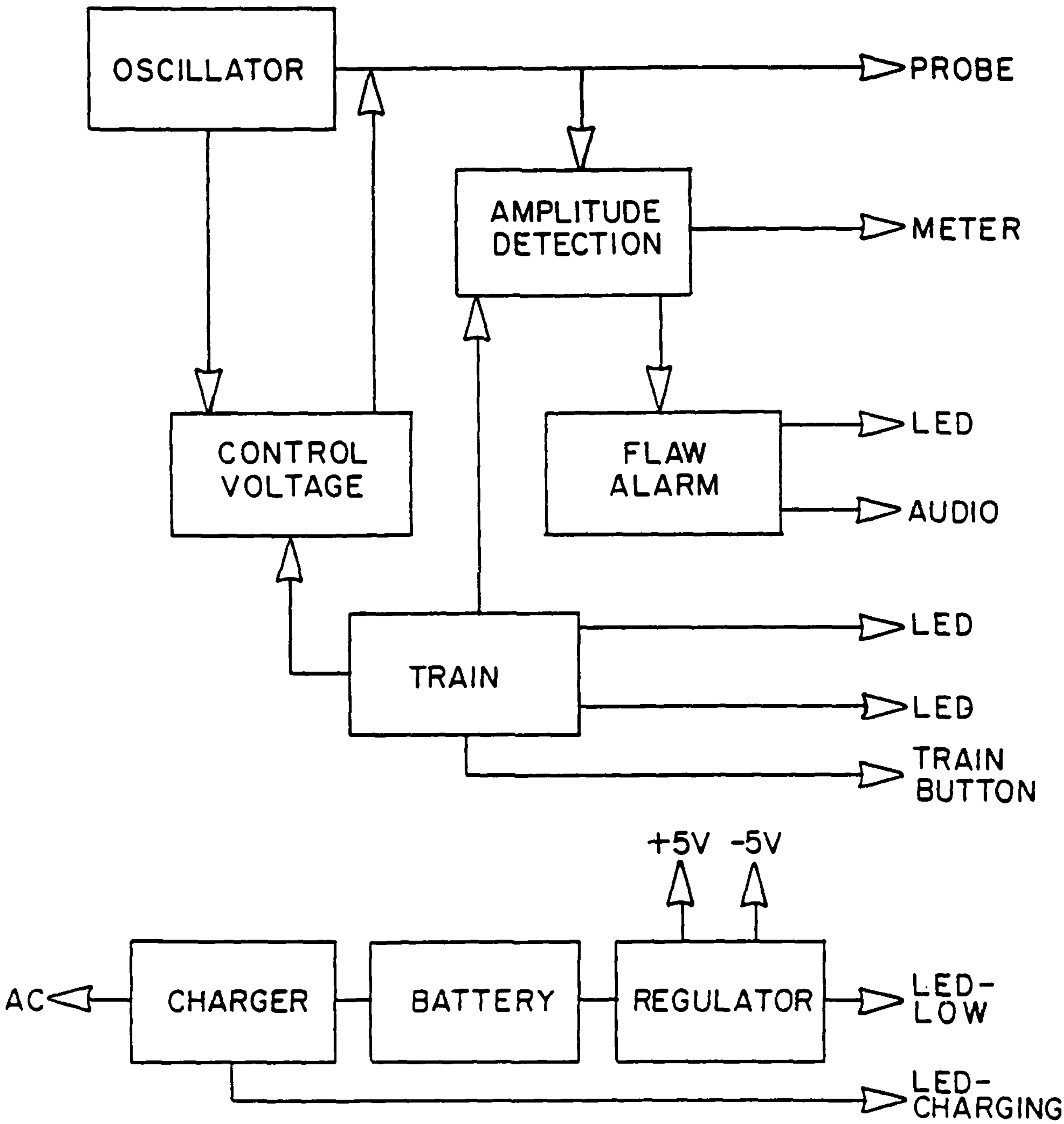


Figure 4-1. Functional Block Diagram

4-11. Cracks divert the eddy currents, affecting their strength and their opposition to the coil field and so further change the effective resistance and inductance of the probe coil.

4-12. LIFT-OFF EFFECT.

4-13. Eddy currents in the metal are reduced as the probe is lifted off the surface of the metal. There is less opposing flux and an increase in probe coil inductance. There is a less energy loss and a corresponding reduction in effective resistance. Flaw Detector oscillator frequency is governed by the inductance of the probe coil. The rise of inductance with lift off causes a corresponding fall in oscillator frequency. The reduced probe resistance with lift-off tends to cause an increase in the amplitude of oscillations and therefore alter the meter deflection. However, to correct for lift-off effect, the Flaw Detector circuitry adds electronic resistance as lift off occurs.

4-14. TRAINING.

4-15. The "train" sequence enables the Flaw Detector circuitry to add exactly the right amount of electronic resistance just as lift-off occurs, to exactly balance the fall of effective probe resistance. This causes the amplitude of oscillations to remain constant, and the deflection of the meter is not changed.

4-16. ELECTRONIC RESISTANCE.

4-17. Lift-off causes a change in probe frequency. This frequency is used to develop a control voltage (see Figure 4-1). The control voltage varies the electronic resistance of the probe coil. As the probe is lifted, the control voltage, which in turn increases the resistance to maintain a constant amplitude as follows:

Electronic Resistance = K x Control Voltage

4-18. TRAIN FUNCTION.

4-19. The train function sets the value of K so that when the probe is lifted off the metal just the right amount of resistance is applied to maintain a constant amplitude to the amplitude detection circuit and to the meter and flaw alarm. When the train button is pressed with the probe on the metal surface, the lower LED illuminates. At the same time the control voltage and the meter are both zeroed. As the probe is lifted off, the control voltage changes (since the frequency is changing) and the meter circuit will be unbalanced (since the coil resistance is changing). When the control voltage has changed by a pre-determined amount, a digital circuit adjusts the electronic resistance constant K until the coil amplitude is the same as it was before lift-off; that is, until the meter circuit is balanced. The damping constant K is now close to the correct value, so that changes in lift-off will cause little change in the meter circuit. Further raising and lowering of the probe sets K with greater accuracy.

4-20. FERROUS METALS.

4-21. As the probe approaches ferrous metals, the magnetic domains cause an increase in flux, overriding the opposing field of eddy currents, and increasing the probe inductance. Therefore, lift-off causes reduced inductance and increases oscillator frequency. The electric circuit allows for this when developing the control voltage for ferrous metals.

4-22. BATTERY.

4-23. Figure 4-1 shows the battery charger, battery (two 6V NICAD cells), regulator, output (-5V and +5V), low battery indicator LED, and charging indicator LED.

4-24. PCB1 FUNCTIONS.

4-25. Control Signal.

4-26. Integrated circuit IC4 divides the coil frequency to approximately 120 KHz, and integrated circuit IC8(a) provides 2-microsecond -ve pulses at pin 3. The integrated circuit IC5 is a monostable multivibrator that provides +ve-going square pulses at pin 3. Pin 11 of integrated circuit IC8(c) gives +ve-going square pulses, rising 2 microseconds later.

4-27. Transistor TR5 is a temperature-compensated, constant-current source charging C17 linearly from the end of each +ve-going square pulse until the start of the next square pulse. No charging occurs during the 2-microsecond period. (See waveforms in Figure 4-2.) Integrated circuit IC9(c) charges C3 to peak of C17, and IC1 buffers C3 to provide the control voltage signal.

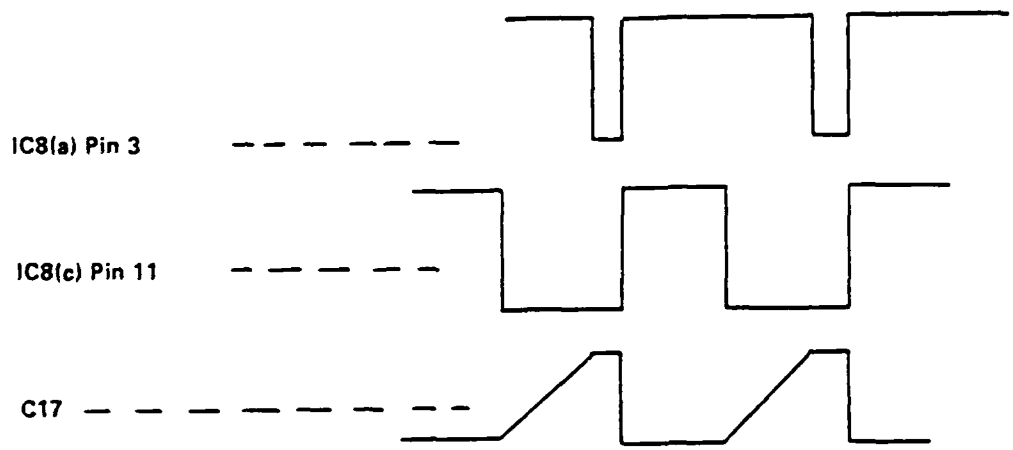


Figure 4-2. Control Signal Waveforms

4-28. Schmitt Trigger.

4-29. Integrated circuit IC3 acts as a Schmitt Trigger, going +ve when the control signal is more than 0.5V above its -1V reference level. The +ve signal activates the Successive Approximation Register (SAR) of PCB2. When the control signal is less than 0.15V above its -1V reference level, IC3 output goes -ve and through IC8(d) causes IC9(a) to provide a rezero function on PCB2.

4-30. TRAIN Sequence.

4-31. When the TRAIN button is pressed, IC12(c) pin 10 goes -ve for one-to-two seconds. This provides a rezero function but also causes, through IC12(b), the SARs IC13 and IC14 to operate. These adjust the period of the monostable until the control signal is equal to the potential at pin 2 of IC2; that is, -1V.

4-32. Ferrous Metals.

4-33. Integrated circuit IC18 provides phase reversal for the control signal.

APPENDIX B

PROPOSED MILITARY STANDARD XXX,
"EDDY CURRENT PROBE PERFORMANCE CHARACTERIZATION"

NOTE: This second draft, dated March 1988, prepared by the U.S. Army Materials Technology Laboratory, Watertown, MA 02172-0001, has not been approved and is subject to modification. DO NOT USE FOR ACQUISITION PURPOSES. (Project NDTI-0094)

MIL-STD-XXX

(PROPOSED)

MILITARY STANDARD

EDDY CURRENT PROBE PERFORMANCE CHARACTERIZATION

AMSC N/A

/AREA NDTI/

FOREWORD

Eddy current probes are used for the nondestructive inspection of parts or structures made of electrically conducting materials. These inspections are intended to find material defects, such as fatigue cracks, which may cause the part or structure to be unsafe or unfit for further service. Therefore, it is important for the inspector performing these tests to be aware or at least assured that the probes being used meet a minimum satisfactory level of performance. This document is intended to establish a uniform test methodology and set minimum criteria for determining acceptable eddy current probe performance.

1. SCOPE

1.1 <u>Scope.</u> This standard contains procedures for characterizing the performance of eddy current probes (air or ferrite core, wire wound, shielded or unshielded, absolute). Some construction details such as alignment of the coil in the probe body are specified. The test blocks used in these tests shall not be confused with a calibration standard. This test method measures the coupling of the probe coil to the test materials. This standard does not address the issue of determining the best coils or probes for specific inspections nor is it intended to be used to quantify defect sizes found during inspections. The test method detailed here merely determines whether an eddy current probe response meets the performance levels specified in this document (5.2.5). This is not a calibration, it is a characterization.

2. REFERENCED DOCUMENTS

2.1 Government. Unless otherwise specified, the following specifications, standards, and handbooks of the issue listed in that issue of the Department of Defense Index of Specifications and Standards (DoDISS) specified in the solicitation form a part of this standard to the extent specified herein.

STANDARDS

MILITARY

MIL-STD 410 Nondestructive Testing Personnel Qualification and Certification

(Copies of specifications, standards, handbooks, drawings, publications, and other Government documents required by contractors in connection with specific acquisition functions should be obtained from the contracting activity or as directed by the contracting officer.)

2.2 Other publications. The following document(s) form a part of this standard to the extent specified herein. Unless otherwise specified, the issues of the documents which are DoD adopted shall be those issued in the DoDISS specified in the solicitation. The issues of the documents which have not been adopted shall be those in effect on the date of the cited DoDISS.

American Society for Testing and Materials (ASTM)

ASTM E 268 - Definition of Terms Relating to Electromagnetic Testing.

(Application for copies should be addressed to ASTM, 1916 Race Street, Philadelphia, PA 19103)

2.3 Order of precedence. In the event of a conflict between the text of this standard and the references cited herein, the text of this standard shall take precedence.

3. DEFINITIONS

3.1 Eddy current test blocks. For the purposes of the test method described in this document, these are blocks, one made of an aluminum alloy and one made of a titanium alloy (see 5.2.2.1), to which an active eddy current probe is applied. Both the aluminum and titanium blocks are required for this test.

3.2 Mathematical symbols used. In the following definitions, N means any number.

3.2.1 $|N|$ The magnitude of N, regardless of N being positive, negative, or a vector quantity.

3.2.2 * Multiply.

3.2.3 $\sqrt{N}$ The square root of N.

3.2.4 $(N)^2$ N squared, i.e. N * N.

3.2.5 Δ Delta, the change in a particular quantity, i.e. ΔN means the change in N.

3.2.6 j A symbol used in electrical engineering to represent $\sqrt{-1}$. It is associated with the restriction of electrical flow due to capacitors and coils.

4. GENERAL REQUIREMENTS

4.1 Use of the test blocks. The test blocks used in the following tests shall not be confused with a calibration standard. This test method measures the coupling of the probe coil to the test materials and shall not be used to evaluate flaw sizes in the actual parts being inspected. The test method detailed here merely determines whether an eddy current probe response meets the performance levels specified in this document only (see 5.2.5). This is not a calibration, it is a characterization.

4.2 Personnel qualifications. The tests required by this standard shall be performed by personnel certified in eddy current testing to at least the Level II requirements of MIL-STD-410.

5. DETAILED REQUIREMENTS

5.1 Requirements.

5.1.1 Purpose. The purpose of these tests is to identify eddy current probes having either low sensitivity or poor workmanship or both and to prevent probes so identified from being brought into service.

5.1.2 Application guidance. Characterization of eddy current probes will be carried out when deemed necessary by the procuring activity. Eddy current probes selected for testing shall be characterized in accordance with the procedures outlined in this document.

5.2 Test method. Impedance measurements are made using test blocks of two different conductivities. The probe impedance change (ΔZ) is calculated from these data and compared to the minimum ΔZ levels established for similar probes operating at that frequency.

5.2.1 Scope. This test method shall be used on all eddy current inspection probes which are identified for performance characterization testing.

5.2.2 Description of needed test equipment. The test instrument shall be a commercial impedance analyzer with a built in oscillator capable of driving a current in the probe at the probe's nominal operating frequency. The output shall display the probe impedance in either polar form, giving a magnitude and a phase angle or rectangular form, giving resistive and reactive components of the impedance or both. This instrument shall be calibrated according to the manufacturer's specifications at the required interval.

5.2.2.1 Test blocks. For probes of all frequencies the test blocks shall consist of two pieces, both being 3/4 in. (1.9 cm) thick with electrical-discharge-machined (EDM) tapered holes and electrical-discharge-planing of one of the wide faces of the block. All EDM surfaces shall be polished to a finish $\leq$ 590 μin. (15 μm rms). One piece shall be fabricated from a 7075-T6 aluminum alloy piece (conductivity at 273 K (0°C) = 5.29 $\mu\Omega\cdot$cm), and the second, from a 6Al-4V-Ti piece (conductivity at 273 K (0°C) = 167.5 $\mu\Omega\cdot$cm).

These blocks shall have tapered holes for testing bolt hole probes. The holes in the test blocks shall have tapers ranging from (nominal dimension + 1.5%) to (nominal dimension - 1.5%) so that slightly oversized and undersized bolt hole probes may be insured of a snug fit during the inspection. The tapered holes shall be made for all the nominal sizes of bolt hole probes to be inspected. The edges of the holes shall be spaced 3/4 in. (1.9 cm) apart from each other and from the block edges. The large end of the tapered holes shall connect to the polished EDM surface. Figure 1 shows an example of a simplified test block with holes for testing three sizes of bolt hole probes.

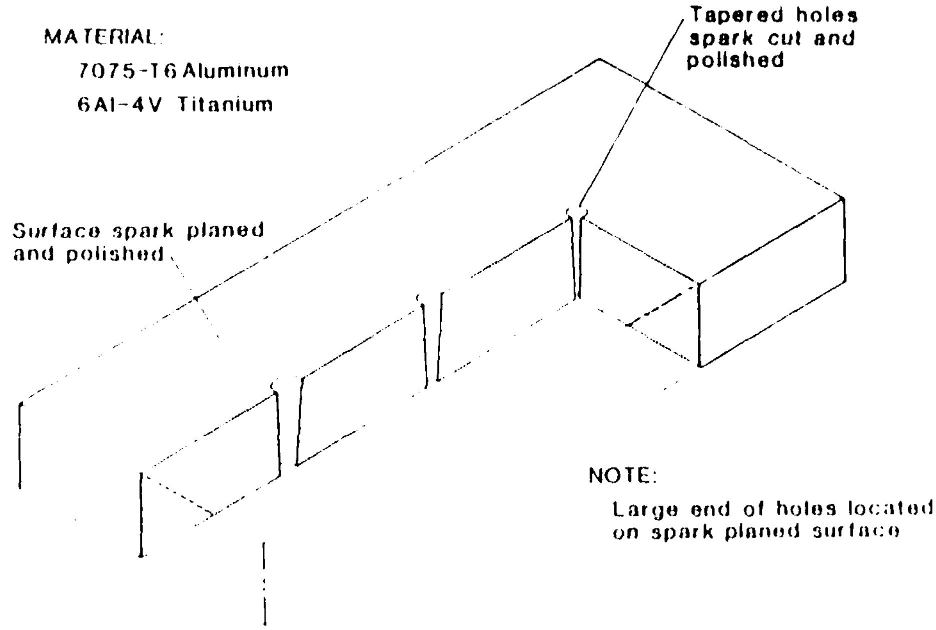


FIGURE 1 Schematic of test block.

5.2.3 Visual Inspection. Check workmanship of the probe. Physical dimensions of the probe must be within tolerances specified in the purchase requisition. Glue or epoxy on the probe face must conform to the contours of that probe face. Check for proper shape of probe body for intended application.

5.2.3.1 Construction details. The details outlined here are not intended to limit probe body configurations, rather, they are to be used as guidelines. Specialized probe configurations can be designed to suit particular applications. The procuring activity is ultimately responsible for determining if the probe configurations meet the specifications agreed upon with the probe manufacturer.

5.2.3.1.1 Bolt hole probes. The coil's ferrite core of this type of probe can project slightly beyond the contour of the probe face. This minimizes liftoff effects by permitting the active element of the probe (the coil) to follow the surface of a hole which may no longer be circular. The coil windings must be recessed from the probe face so that wear does not occur on the coil windings and ruin the probe. At a position 180 degrees from the active end of the coil, some mechanism must be provided to keep the active end of the coil in contact with the surface of the hole during an inspection. The coil shall be perpendicular to the axis of the probe body and have its axis along the probe radius.

5.2.3.1.2 Surface probes. The face of this type of probe must be flat and free of blemishes, glue or epoxy which would cause the probe to not sit flat on the surface to be inspected. As with the bolt hole probes, the coil

windings must be recessed from the probe face for the same reasons. The coil shall have the same axis as the probe body.

5.2.3.1.3 Pencil probes. As the name implies, the useful end of this type of probe is shaped like the pointed end of a pencil. The dimensions of the tip must allow inspection of the parts for which it was designed.

5.2.4 Performance test.

5.2.4.1 Measurement techniques. Impedance values can be expressed in different ways. Most commonly, impedances are given in either rectangular or polar form. In polar form the impedance is expressed as a magnitude, Z, with a corresponding phase angle, θ, and often appears as $Z\angle\theta$. The rectangular form expresses the magnitude as a combination of a resistive component, R, and a reactive or imaginary (denoted by j) component, X. This form often appears as $R \pm jX$. A more thorough discussion of these concepts can be found in Appendix A. Figure 2 shows two points measured in both forms and the resulting impedance change (ΔZ) calculation. This is typical of the way impedance changes are measured on actual eddy current probes using the two-conductivity block method. In this method, the impedance of a probe is first measured on a titanium test block, then on an aluminum test block, and the difference between these two measurements is calculated.

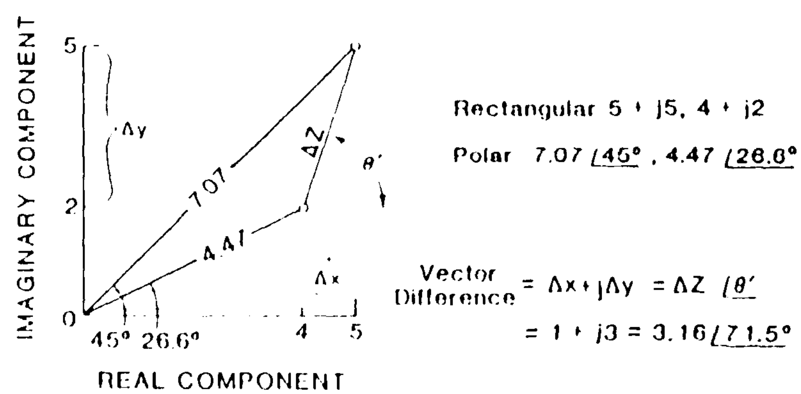


FIGURE 2. Rectangular and polar coordinates and resulting ΔZ

The reason for the use of both the polar and rectangular forms of the impedance is that certain characteristics may be easier to spot in one form while certain calculations are correctly performed in the other form.

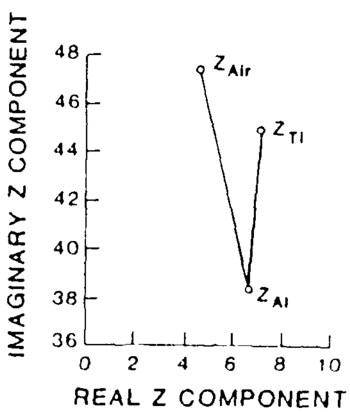
5.2.4.2 Test method. All performance tests shall be conducted within the temperature range of 60° to 80° F (16° to 27° C).

In the measurement sequence, the probe is positioned away from any metal part or surface and is attached to the impedance measuring instrument. Probe impedance in air (magnitude and phase) is recorded to check for shorts or opens and proper impedance match of the probe to an eddy current instrument.

Phase angles out of the range of (+)80 to (+)90 degrees indicate possible shorts or opens in the probe, or a mismatched drive frequency. The impedance magnitude, $|Z|$, of the probe in air should be within the proper range as specified by the eddy current instrument manufacturer.

Next, the probe is positioned on or in the titanium test block. The specific orientation depends on the probe type. Surface probes should be moved to four different spots on the face of the block, well away from both edges and holes, and the impedance recorded in rectangular components, R and X (resistive and reactive components). Similarly, bolt hole probes should be rotated in the tapered hole to four different positions for measurement. Significant variations (scatter) among the four measurements (> 4%) indicate that the probe must be held more securely (surface probe) or made to fit more snugly in the tapered hole (bolt hole probe) and the measurements repeated. An independent check can be made by another operator to help rule out individual technique as the source of the variation. Alternatively, the operator can test a probe which is known to be good. The use of a calibrated impedance analyzer is important to help rule out the instrument as the source of variability.

Average values of R and X are then determined from the four repeat measurements. This series of measurements is then repeated using the aluminum block and appropriate values of ΔZ are determined as shown in Figure 3 and the worksheet found in Appendix B.



	Z_{Real} R (Ω)	$Z_{Imag.}$ X (Ω)
Air	4.45	47.40
Al	6.62	38.36
Ti	7.10	44.93

	$\Delta R + j\Delta X = \Delta Z \angle\theta'$
ΔZ (Air-Al)	$-2.17 + j9.04 = 9.30\angle 103.5°$
ΔZ (Ti-Al)	$0.48 + j6.57 = 6.59\angle 85°$

FIGURE 3. Example of impedance plane plots of ΔZ measurements.

Values of ΔZ are then compared to minimums established for the probe type being evaluated for the accept/reject determination (see 5.2.5). Worksheets for the calculation of results can be found in Appendix B.

5.2.5 Performance levels. The minimum acceptable magnitude of ΔZ for all probes operating at a frequency of 100 kHz or greater is 2.0 Ω. The value of the probe impedance in air must match the manufacturer's specification within 5%. The proper range of the phase of the probe (θ), measured in air (Appendix B 40.3), is between (+) 80° and (+) 90°. Failure of a probe to meet any of these criteria is sufficient cause for rejection. These specifications will be revised and expanded once a larger data base has been established. To contribute data from these tests to the probe performance data base see Appendix C.

5.2.6 Measurement scatter. On repeat determination of impedance for a single probe, it is recommended that the measurements be within 4% of each other. Measurement scatter greater than this may be indicative of problems with either operator technique or measurement equipment.

5.3 Calibration and standardization. Calibrate impedance measuring instruments according to manufacturer's instructions at the recommended intervals.

6. NOTES

6.1 Intended use. This standard contains requirements and guidelines for the inspection and performance screening of eddy current nondestructive testing probes.

6.2 Subject term (key word) listing. Eddy current probes, nondestructive testing, probe standards, performance testing.

APPENDIX A

VECTOR IMPEDANCE TUTORIAL

10 General.

10.1 What is a vector? A vector is a quantity that has a magnitude and direction. For example, the distance a car has traveled along a highway can be expressed as a vector; 100 miles heading east. In this case, the magnitude is 100 and the direction is east. Now, instead of calling the directions north, south, east, and west, imagine calling them by angles where north is 0 degrees, east is 90 degrees, south is 180 degrees, and west is 270 degrees. To express the journey of the car as a position vector then would be; magnitude = 100 miles, direction = 90 degrees. To represent this information on a graph. the magnitude is shown as an arrow 100 units long with an orientation of 90 degrees (Figure A1).

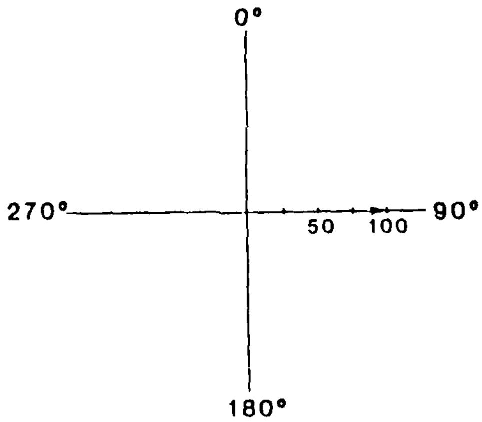


FIGURE A1. Position Vector

20 Specific.

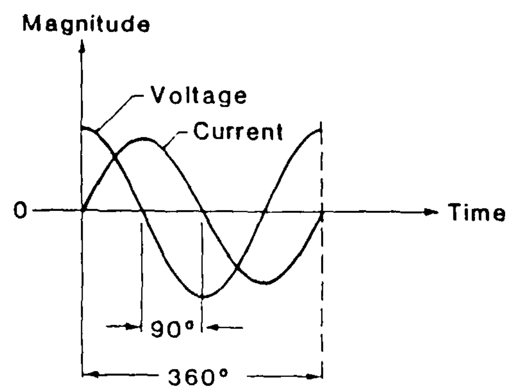
20.1 Periodic waveforms. Electrical measurements often involve quantities such as voltage and current that can vary with time. If these variations repeat consistently in a measurable amount of time then they are known as periodic waveforms. The length of time a waveform lasts before it repeats is known as the period. Different periods can last different amounts of time, but a single period always has 360 degrees associated with it. Another way to think about this would be that 90° always represents the 1/4 point along a waveform but the amount of time needed to get to that point from the beginning will not always be the same.

Different points on the waveform in one period are referred to by their positions in degrees along the waveform. Thus, 0° would be the beginning, 180° the midpoint, and 360° the end of the waveform, but 360° is also the beginning of the next period and therefore is 0° on the next cycle.

The size of the waveform can be measured from its maximum and minimum points, but more commonly a technique known as the "rms" method is used. This is similar to, but not the same as, an average value of the waveform.

20.2 Impedance as a vector. If one were to pass a periodic or alternating electric current (AC) through a two terminal device (e.g., resistor, coil, or capacitor) a voltage could be measured across the terminals of that device. The impedance of this device is defined as the ratio of the rms value of that voltage to rms value of the current (Figure A2).

The difference in the position of a point on the voltage waveform compared to the corresponding point on the the current waveform is the phase angle, θ, between the voltage and current. This angle is often measured in degrees. If the voltage point occurs before the corresponding current point (as is the case in a coil) then the voltage is said to be leading the current and have a positive phase angle. If the voltage point occurs after the corresponding current point (as is the case in a capacitor) then the voltage is said to be lagging the current and have a negative phase angle. Now the impedance can be expressed as a magnitude, $|Z|$, and a direction, θ, (in the sense of the voltage lagging or leading the current by a certain amount) and fits the definition of a vector.



Voltage leading current by 90°
$\theta = (+)\ 90°$

FIGURE A2. Periodic voltage and current waveforms and resulting phase relationship.

20.3 Adding and subtracting vectors. The addition and subtraction of vectors must be done in rectangular coordinates. If the phase angles are ignored and just the polar magnitudes are used for these operations then the information contained in the associated phase angles is lost and the result will be incorrect.

APPENDIX B

WORKSHEET FOR CALCULATION OF RESULTS

10 General.

10.1 Scope. This appendix provides mathematical formulas used for the calculation of test results and worksheets for recording measurements and calculating results. It is recommended that the worksheet in this document be left blank and photocopied for each probe tested.

20 General requirements. These measurements should be performed using a test instrument which displays impedance in rectangular coordinates. Instruments displaying polar coordinates may be used, but the impedance measurements need to be converted to rectangular form.

20.1 Polar to rectangular conversion. The conversions from polar ($Z\angle\theta$) to rectangular (R+jX) can be performed using the following formulas:

$$R = Z * \cos\theta \qquad X = Z * \sin\theta$$

The use of a calculator with trigonometric functions is recommended. The abreviation cos is used for the cosine function, and the abreviation sin is used for the sine function.

20.2 Rectangular to polar conversion. The conversions from rectangular (R+jX) to polar ($Z\angle\theta$) can be performed using the following formulas:

$$Z = \surd(R^2+X^2) \qquad \theta = \tan^{-1}(X/R)$$

The abbreviation tan is used for the tangent function. The $\tan^{-1}$, or inverse tangent, function returns a value that is a measure of an angle and can be in either degrees or radians. When using a calculator to determine the $\tan^{-1}$, care should be taken to determine if the answer is in degrees or radians as the numerical values which represent the same angle are quite different in each case.

30 Detail requirements. After recording the measured impedances, it will be necessary to perform few calculations.

30.1 Average value. This involves adding the four measurements ($R_1+R_2+R_3+R_4$ and $X_1+X_2+X_3+X_4$), dividing the totals by four and recording those results in the appropriate space on the worksheet (see Appendix B 40).

30.2 Impedance magnitude, $|Z|$. $|Z| = \surd(R^2+X^2)$

30.3 Measurement scatter. A percentage value obtained by choosing the highest and lowest values from the four impedance magnitudes and applying the following formula:

$$[(\text{highest val.} - \text{lowest val.}) \div \text{highest val.}] \times 100.$$

Record these values and this result in the alloted space.

30.4 Change in impedance (ΔZ). The average probe impedance calculated for aluminum is subtracted from the average calculated for titanium. The impedance change in rectangular form is converted to a polar magnitude. Record this value in the last section of the worksheet.

40 Measurement Worksheet.

40.1 Probe identification.

40.1.1 Manufacturer and serial no. ______________________________

40.1.2 Probe type. Bolt hole (size) ____________, surface _________,

other (specify) ____

40.1.3 Nominal operating frequency. ____________________________

40.1.4 Specified impedance in air. ______________________________

40.2 Measure Temperature.

40.2.1 Range. The test shall be conducted within the temperature range of 60°F to 80°F (16°C to 27°C).

40.2.2 Ambient room temperature. ________________°C.

40.3 Measure Probe Impedance in Air. Position the probe away from any metal, attach it to the impedance measuring instrument and set the frequency for the nominal operating frequency of the probe being tested. Record the impedance in rectangular coordinates. Calculate and record the impedance magnitude, $|Z|$, and angle, θ. If the impedance instrument being used is capable of measuring in both polar and rectangular coordinates then switching the instrument between these two methods of presentation is permissible for this single measurement only (see Appendix A 20.3).

		R		X		$\lvert Z\rvert$	θ
Impedance =	(1)	_______	+ j	_______	(Ω) ,	_______(Ω) ,	______(deg)

Check $|Z|$ and θ for proper values (see 5.2.5).

40.4 Measure Probe Impedance on Test Blocks.

40.4.1 Impedance Using Titanium Block. Start the measurement sequence with probe in position number 1 using the titanium test block (Ti marked on end of block). Refer to Figure B1 for surface probe orientation and Figure B2 for bolt hole probe orientation. Record impedance measurements, in rectangular coordinates, for each of the four positions indicated. Calculate and record the impedance magnitude, |Z|, for each measurement. The tip of surface probes should not touch the edges of the block or holes. The coil of a bolt hole probe should be near the center of the thickness of the test block.

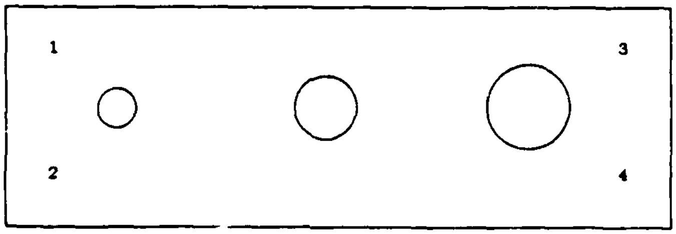


FIGURE B1. Surface Probe Positions

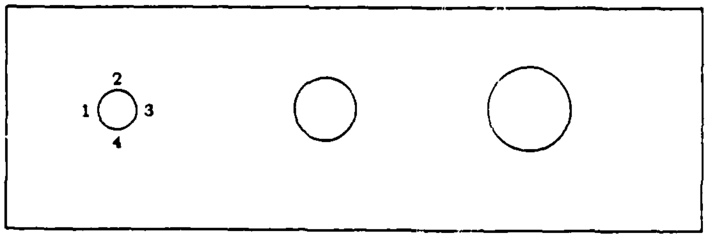


FIGURE B2. Bolt Hole Probe Positions

		R		X	|Z|
Impedance =	(1)	_______	+ j	_______(Ω) ,	_______(Ω)
	(2)	_______		_______(Ω) ,	_______(Ω)
	(3)	_______		_______(Ω) ,	_______(Ω)
	(4)	_______		_______(Ω) ,	_______(Ω)

Add each column of four numbers to get total.

Total = _______ + j _______ (Ω)

Divide the total by 4 to get average value.

Average = ________ + j ________ (Ω)

Subtract lowest |Z| from highest |Z| and divide by highest. Multiply this value by 100 to get measurement scatter.

Highest |Z| = ________ Measurement Scatter = ____________ %

Lowest |Z| = ________

40.4.2 Impedance Using Aluminum Block. Start measurement sequence with probe in position number 1 using the aluminum test block (A1 marked on end of block). Refer to Figure B1 for surface probe orientation and Figure B2 for bolt hole probe orientation. Record impedance measurements, in rectangular coordinates, for each of the four positions indicated. Calculate and record the impedance magnitude, |Z|, for each measurement. The tip of surface probes should not touch the edges of the block or holes. The coil of a bolt hole probe should be near the center of the thickness of the test block.

		R		X	|Z|
Impedance =	(1)	______	+ j	______(Ω) ,	______(Ω)
	(2)	______		______(Ω) ,	______(Ω)
	(3)	______		______(Ω) ,	______(Ω)
	(4)	______		______(Ω) ,	______(Ω)

Add each column of four numbers to get total.

Total = ________ + j ________ (Ω)

Divide the total by 4 to get average value.

Average = ________ + j ________ (Ω)

Subtract lowest |Z| from highest |Z| and divide by highest. Multiply this value by 100 to get measurement scatter.

Highest |Z| = ________ Measurement Scatter = ____________ %

Lowest |Z| = ________

40.5 <u>Change in Impedance, ΔZ.</u> Obtain ΔZ by subtracting the average value of impedance measured on the aluminum test block from the corresponding value measured on titanium according to:

$$\Delta R + j\Delta X = (R_{Ti} - R_{Al}) + j(X_{Ti} - X_{Al})$$

R X

Ti avg. Impedance = ________ + j ________ (Ω)

Al avg. Impedance = ________ + j ________ (Ω)

ΔR ΔX

Probe ΔR + jΔX = ________ + j ________ (Ω),

Convert ΔR + jΔX to |ΔZ| using:

$$|\Delta Z| = \sqrt{(\Delta R)^2 + (\Delta X)^2}$$

$(\Delta R)^2$ = __________ , $(\Delta X)^2$ = __________ , $(\Delta R)^2 + (\Delta X)^2$ = __________

|ΔZ| = ____________

APPENDIX C

PROBE PERFORMANCE REPORTING FORM FOR ADDITIONS TO PROBE PERFORMANCE DATA BASE

10 General.

10.1 Scope. This reporting form is the means by which performance data can be accumulated for a large number and variety of eddy current probes. The only restriction that applies to this form is that the probes must have been tested in accordance with the method defined in this document (MIL-STD-XXX). However, if there is additional data which may be of potential value, please feel free to include it also. As with the worksheet, it is recommended that this sheet be left blank and photocopied when needed. This data base is maintained by researchers at the National Bureau of Standards in Boulder, Co. Anyone with test data to submit or conversely, anyone seeking information on the performance of eddy current probes can contact:

U. S. Army Materials Technology Laboratory
Watertown MA 02172-0001

20 Survey Questions.

20.1 What test instrument did you use to measure the impedance?

Name - ____________________

Manufacturer - ____________________

Model Number - ____________________

Descriptive info - ____________________

____

____

20.2 Was the standard easy to use? ____________________

20.3 Why? ____________________

____

____

20.4 What problems did you encounter? ____________________

____

____

____

20.5 Comments. Please feel free to expand on your answers and include any comments or concerns you might have. Attach extra sheets if needed.

30 Specific.

30.1 Probe identification.

30.1.1 Manufacturer and serial no. ______________________________

30.1.2 Probe type. Bolt hole (size) ________ __, surface __________ other (specify) ____

30.1.3 Nominal operating frequency. ______________________________

30.1.4 Specified impedance in air. ______________________________

30.2 Probe test data.

30.2.1 Probe Impedance in Air.

		R		X		Z		θ
Impedance =	(1)	______	+ j	______	(Ω) ,	______	(Ω) ,	______ (deg)

30.2.2 Impedance Using Titanium Block

		R		X		|Z|	
Impedance =	(1)	______	+ j	______	(Ω) ,	______	(Ω)
	(2)	______		______	(Ω) ,	______	(Ω)
	(3)	______		______	(Ω) ,	______	(Ω)
	(4)	______		______	(Ω) ,	______	(Ω)

Average = ________ + j _______ (Ω), Measurement Scatter = __________ %

30.2.3 Impedance Using Aluminum Block

		R		X		|Z|	
Impedance =	(1)	______	+ j	______	(Ω) ,	______	(Ω)
	(2)	______		______	(Ω) ,	______	(Ω)
	(3)	______		______	(Ω) ,	______	(Ω)
	(4)	______		______	(Ω) ,	______	(Ω)

Average = ________ + j _______ (Ω), Measurement Scatter = __________ %

30.2.4 <u>Change in Impedance, ΔZ</u>

$$\Delta R + j\Delta X = (R_{Ti} - R_{Al}) + j(X_{Ti} - X_{Al})$$

R X

Ti avg. Impedance = ______ + j ______ (Ω)

Al avg. Impedance = ______ + j ______ (Ω)

ΔR ΔX

Probe $\Delta R + j\Delta X$ = ______ + j ______ (Ω),

Convert $\Delta R + j\Delta X$ to $|\Delta Z|$ using:

$$|\Delta Z| = \sqrt{(\Delta R)^2 + (\Delta X)^2}$$

$(\Delta R)^2$ = ________ , $(\Delta X)^2$ = ________ , $(\Delta R)^2 + (\Delta X)^2$ = ________

$|\Delta Z|$ = __________

APPENDIX C

LIFTOFF TRAINING PROCEDURE FOR THE HOCKING UH-B EDDY CURRENT INSTRUMENT (FROM TO 33B2-7-11, 28 FEBRUARY 1986, PRELIMINARY)

Section V

OPERATING INSTRUCTIONS

5-1. CONTROL AND INDICATOR FUNCTIONS.

5-2. Table 1-1 lists functions of controls and indicators. The controls and indicators are illustrated in Figure 1-2. Key numbers in Figure 1-2 appear in Table 1-1 to aid in item identification.

5-3. OPERATING INSTRUCTIONS.

5-4. SETTING UP FOR OPERATION. (For 200KHz probe on aluminum test block.)

NOTE

If instrument is to be used in a poorly lighted area, set METER switch to position marked by a star to illuminate meter.

a. Insert plug of probe cable (item c, paragraph 1-15) in socket (13, Figure 1-2) and connect cable to probe (item b, paragraph 1-15).

b. Set FREQUENCY switch (10, Figure 1-2) at 200 KHz.

c. Set ALARM switch (5, Figure 1-2) at desired alarm mode. (Refer to KEY NO. 5 in Table 1-1 for options.)

d. Set METAL selector switch (19, Figure 1-2) at Al.Mg.

e. Set ALARM LEVEL (11, Figure 1-2) at required setting. (Refer to KEY NO. 11 in Table 1-1).

f. Set MODE switch (7, Figure 1-2) to normal. (Refer to KEY NO. 7 in Table 1-1 for options.)

g. Set OFF/ON/BATT-TEST switch (8, Figure 1-2) at ON. Set GAIN to approximately 500.

CAUTION

Use light contact pressure when placing end of probe on metal. This will minimize wear on probe.

NOTE

The procedure in the steps following is termed training; that is, acclimatizing the instrument to the metal to be scanned. Once trained, the instrument can be used to scan a series of items of the same metal without repetition of the training process. However, changing metals requires retraining.

h. Place end of probe on a sound part of TBAL TEST BLOCK (item d, paragraph 1-15) away from any edge.

NOTE

During training, hold probe as near perpendicular to the metal surface as possible.

i. Press and release TRAIN pushbutton (15, Figure 1-2). The adjacent lower yellow LED (14, Figure 1-2) lights. (Figure 5-1 (1))

NOTE

Raising and lowering the probe in steps j, h, and l should be done smoothly (about 1/3 second for each move).

j. Raise probe very slightly until adjacent upper yellow LED (14, Figure 1-2) lights (lower LED goes off). (Figure 5-1 (2)) If upper LED does not light, METAL selector switch or frequency maybe at wrong setting.

k. Lower probe gently to metal surface. Lower yellow LED lights and upper LED goes off. (Figure 5-1 (3))

l. Repeat steps j and k for two or three cycles. After the last cycle, the probe must be left resting on the metal until the training period is complete (both yellow LEDs off). (Figure 5-1 (4))

NOTE

The following steps check lift-off compensation.

m. Place lift-off shim (item f, paragraph 1-15) between the test block being scanned and the end of the probe; then move the probe across the surface.

n. Meter deflection should be less than 5%when GAIN is set at 500. If there is variance greater than 5% meter deflection, repeat training process.

5-5. OPERATION.

5-6. Operation consists of holding the probe in light contact (to minimize wear) with the metal and passing the probe over the surface. Presence of a crack will be indicated by an abrupt movement to the right of the meter needle. Meter needle deflection is greatest when the probe is directly over the crack. Crack severity is indicated by the magnitude of meter needle deflection.

NOTE

Crack severity is a relative indication of crack size or depth. Many factors can influence a reading. Hence, actual crack size or depth cannot be accurately determined by the Eddy Current method.

5-7. Large meter deflections held for long periods of time will cause a very slow change in the zero point. This is less than 2% after full-scale deflection has been held for 15 seconds.)

5-8. The probe may be transferred to different work pieces of like metal without retraining. Small differences in the zero point are corrected by pressing the ZERO button.

5-9. During extended operation, periodically check battery condition by setting OFF/ON/BATT-TEST switch at BATT TEST. (Refer to KEY NOS. 8 and 9 in Table 1-1.) A fully charged battery will sustain eight to ten hours of operation. If the green LED starts to flash the instrument should be recharged before further use.

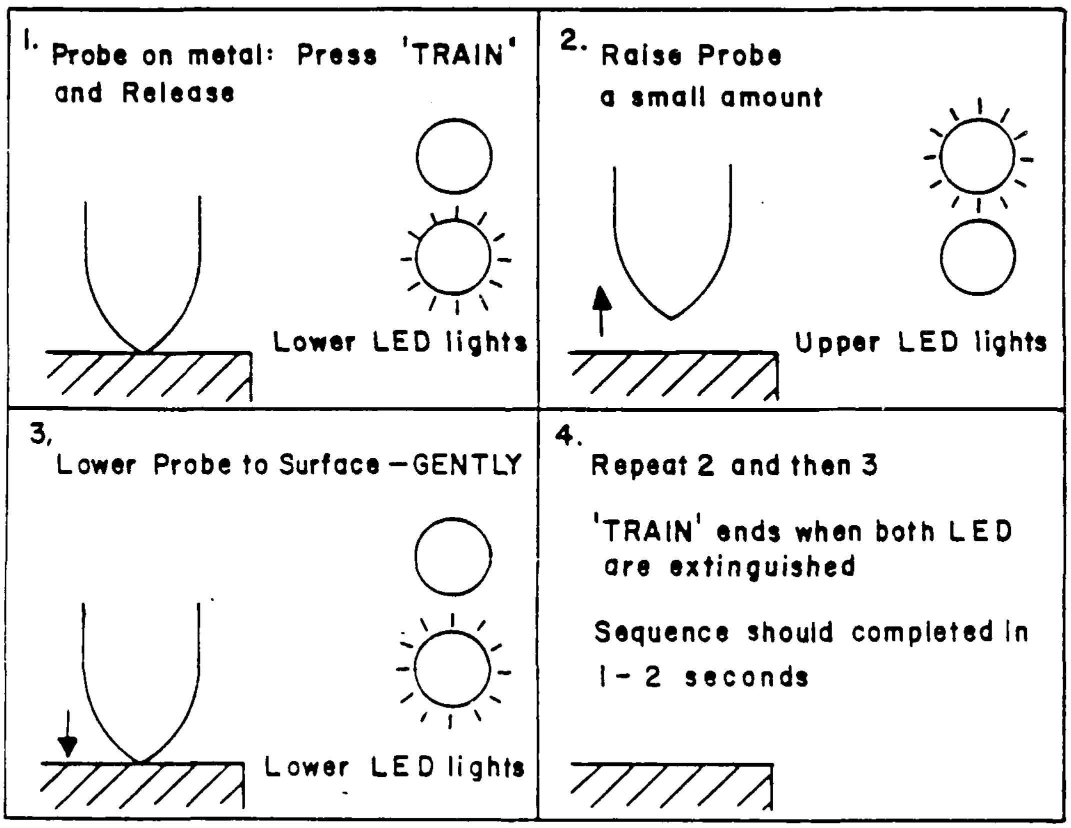


Figure 5-1. Probe

APPENDIX D

EDDY CURRENT PROBE DATA

TABLE D-1. **Flaw Response Measurements from Shielded Probes with Probe on Surface and Perpendicular Orientation (Normalized to Gain=1000, 1=100% Meter Full Scale)**

PROBE	SLOT 1	SLOT 2	SLOT 3	SLOT4	CRACK 1	CRACK 2
1	.226	.570	1.839	3.261	.897	2.375
2	.343	.990	2.703	4.395	1.253	3.312
6	.403	1.171	3.128	4.983	1.476	3.691
7	554	1.502	3.909	6.211	1.808	4.577
20	.792	1.847	3.573	4.814	1.791	4.104
21	.949	2.021	3.629	4.666	1.931	4.052
27	.205	.622	1.983	3.648	.754	2.303
33	1.168	3.141	7.419	11.114	3.087	7.808
36	.892	2.458	6.500	10.096	3.122	7.658
39	.545	1.482	4.786	9.283	1.703	5.578
43	.560	1.509	3.789	5.629	1.903	4.738
57	.420	1.216	3.219	4.988	1.536	3.784
58	.376	1.011	2.903	4.872	1.403	3.469
59	.393	1.118	3.116	5.225	1.375	3.646
62	.626	1.699	5.418	9.954	2.031	5.959
63	.718	2.061	5.533	8.754	2.520	6.418
64	.683	1.859	4.375	6.298	2.249	5.416
71	.865	2.571	7.439	12.476	2.823	8.911
72	.843	2.431	5.817	8.633	3.362	7.590
75	.550	1.471	3.922	6.093	1.925	4.693
76	.568	1.521	3.849	5.953	1.822	4.406
77	.884	2.175	4.410	5.769	3.016	6.291
78	.566	1.567	4.005	6.216	1.743	4.385
79	.813	2.204	4.721	6.555	2.662	6.169
80	.557	1.605	3.651	5.263	2.128	5.085
81	.720	2.032	5.095	7.808	2.399	6.001
82	.478	1.455	3.850	6.067	1.904	4.528
83	1.524	3.523	6.508	8.354	3.951	8.140
84	1.022	2.634	6.734	10.377	3.201	7.983
85	.640	1.758	4.862	8.025	2.157	5.599

TABLE D-2. Flaw Response Measurements from Non-shielded Probes with Probe on Surface and Perpendicular Orientation (Normalized to Gain=1000, 1=100% Meter Full Scale)

PROBE	SLOT 1	SLOT 2	SLOT 3	SLOT4	CRACK 1	CRACK 2
3	.512	1.410	5.038	11.050	1.352	4.918
4	.484	1.369	5.046	11.218	1.352	4.955
9	.457	1.389	4.784	9.947	1.339	4.478
11	.510	1.582	5.764	12.521	1.621	5.855
15	.543	1.545	5.761	13.011	1.644	5.845
18	.593	1.677	5.925	12.590	1.699	5.855
22	.429	1.243	4.453	9.477	1.309	4.409
25	.408	1.232	4.355	9.461	1.190	4.042
26	.418	1.220	4.449	9.373	1.073	3.840
28	.601	1.640	5.569	11.206	1.624	5.434
29	.463	1.341	5.213	11.946	1.376	5.236
32	.553	1.509	5.258	11.074	1.516	5.195
38	.568	1.600	5.815	12.902	1.615	5.800
40	.474	1.367	5.244	12.022	1.353	5.258
41	.488	1.394	5.383	12.343	1.492	5.634
42	.433	1.297	5.020	11.088	1.185	4.239
44	.499	1.346	4.536	9.195	1.073	3.642
46	.461	1.291	4.519	9.468	1.168	3.843
48	.488	1.294	4.429	9.116	1.134	3.881
49	.397	1.052	3.819	7.728	.971	3.738
50	.479	1.373	5.007	10.940	1.428	4.399
52	.524	1.483	5.308	11.468	1.525	5.152
53	.373	1.084	4.269	9.995	1.276	4.868
54	.513	1.493	5.303	11.119	2.031	5.757
56	.485	1.489	5.251	11.210	1.612	5.159
67	.545	1.622	5.651	12.012	1.647	5.588
68	.395	1.184	4.504	10.425	1.208	4.469
69	.358	1.081	4.220	9.754	1.265	4.269
70	.609	1.915	5.805	11.319	1.073	3.860
71	.377	1.088	4.216	9.784	1.581	5.466

TABLE D-3. **Flaw Response Width Measurements from Shielded Probes with Probe on Surface and Perpendicular Orientation (Inches)**

PROBE	SLOT 1	SLOT 2	SLOT 3	SLOT4	CRACK 1	CRACK 2
1	.096	.072	.064	.060	.052	.048
2	.080	.060	.052	.056	.044	.040
6	.076	.060	.052	.056	.044	.044
7	.076	.056	.048	.052	.044	.040
20	.064	.056	.052	.056	.044	.044
21	.064	.052	.052	.056	.044	.048
27	.108	.072	.060	.060	.048	.048
33	.064	.056	.052	.056	.044	.044
36	.072	.056	.052	.052	.048	.048
39	.096	.072	.064	.060	.064	.060
43	.072	.052	.048	.052	.040	.040
57	.084	.060	.056	.052	.044	.044
58	.100	.064	.056	.052	.048	.048
59	.080	.060	.052	.056	.048	.044
62	.092	.072	.064	.060	.060	.060
63	.084	.060	.052	.056	.044	.044
64	.068	.052	.048	.052	.040	.040
71	.088	.064	.056	.060	.052	.052
72	.076	.060	.052	.056	.044	.044
75	.088	.068	.056	.056	.048	.044
76	.076	.056	.056	.052	.044	.044
77	.060	.048	.048	.052	.040	.040
78	.072	.056	.052	.052	.044	.040
79	.064	.048	.048	.052	.040	.040
80	.068	.056	.052	.056	.048	.048
81	.076	.056	.052	.056	.044	.044
82	.076	.056	.048	.052	.044	.040
83	.060	.048	.052	.052	.040	.044
84	.076	.056	.048	.052	.044	.044
85	.080	.060	.052	.056	.044	.044

TABLE D-4. Flaw Response Width Measurements from Non-shielded Probes with Probe on Surface and Perpendicular Orientation (Inches)

PROBE	SLOT 1	SLOT 2	SLOT 3	SLOT4	CRACK 1	CRACK 2
3	.144	.096	.084	.080	.072	.072
4	.152	.096	.084	.080	.072	.072
9	.144	.096	.080	.080	.068	.068
11	.128	.092	.080	.076	.064	.064
15	.144	.100	.084	.080	.064	.064
18	.136	.096	.084	.080	.068	.072
22	.140	.100	.084	.080	.072	.072
25	.144	.096	.084	.080	.072	.072
26	.160	.116	.104	.100	.084	.088
28	.136	.092	.084	.080	.072	.068
29	.164	.104	.088	.084	.072	.072
32	.140	.096	.080	.076	.068	.068
38	.152	.096	.084	.080	.068	.068
40	.156	.100	.092	.084	.072	.069
41	.152	.100	.088	.080	.068	.068
42	.160	.112	.100	[illegible]	.084	.084
44	.152	.112	.104	.100	.088	.088
46	.152	.112	.104	.100	.092	.088
48	.172	.112	.104	.104	.080	.088
49	.150	.116	.096	.100	.088	.098
50	.152	.100	.088	.080	.072	.072
52	.140	.100	.084	.075	.068	.072
53	.148	.108	.092	.088	.068	.076
54	.140	.096	.080	.080	.072	.068
56	.144	.092	.084	.076	.072	.068
57	.140	.096	.084	.080	.068	.068
68	.152	.104	.088	.094	.072	.072
69	.164	.104	.092	.084	.068	.068
70	.116	.104	.100	.104	.068	.088
71	.164	.108	.096	.088	.084	.084

TABLE D-5. Liftoff and Tilt Variation Response from Shielded Probes (Normalized to Gain=1000, 1-100% Meter Full Scale)

PROBE	2 MIL L.O.	6 MIL L.O.	5 DEG. TILT	10 DEG. TILT
1	.098	-.025	.018	.181
2	.113	-1.151	.111	.219
6	.281	-.887	.020	.287
7	.810	.128	.005	.247
20	.632	-2.027	.073	-.152
21	1.057	-1.025	.671	-1.257
27	.093	-.163	-.003	.034
33	1.820	-.406	.287	1.026
36	.392	-1.974	.123	.711
39	.567	-.690	.068	-1.090
43	.645	-.601	.210	.694
57	.258	-1.202	.108	.475
58	.279	-.291	-.024	.012
59	.375	-.315	.023	.385
62	.351	-1.784	.028	-3.529
63	.676	-1.611	.117	1.043
64	.695	-1.378	-.059	.545
71	.301	-4.194	-.326	-11.192
72	.650	-2.632	.008	.457
75	.819	-.080	.055	.658
76	.687	-.536	.041	.224
77	.186	-3.892	.067	.656
78	.763	-.227	-.015	.173
79	.695	-2.196	.119	.379
80	.314	-2.277	.005	.005
81	.506	-2.233	-.034	.369
82	.458	-.717	-.020	.193
83	1.114	-3.343	.510	.356
84	1.270	-.630	.299	.371
85	.745	-.121	.138	.550

TABLE D-6. Liftoff and Tilt Variation Response from Nonshielded Probes (Normalized to Gain-1000, 1-100% Meter Full Scale)

PROBE	2 MIL L.O.	6 MIL L.O.	5 DEG. TILT	10 DEG. TILT
3	.414	.143	.037	.050
4	.312	-.021	-.037	.050
9	.467	-.357	.000	.364
11	.588	.000	-.026	.026
15	.379	-.309	-.060	.000
18	.501	-.806	-.026	.039
22	.143	-1.045	-.033	-1.561
25	.251	-.021	.000	.032
26	.497	-1.773	-3.191	-15.105
28	.565	-1.310	.251	-.418
29	.315	.072	-.054	-.013
32	.458	-.402	-.035	.000
38	.508	-.030	.030	-.045
40	.293	.070	.028	-.028
41	.334	-.097	-.042	.014
42	.641	-.627	-2.057	-13.385
44	.594	-1.336	-1.101	-11.858
46	.523	-1.660	-1.352	-11.563
48	.339	-2.259	-.657	-9.952
49	.251	-2.347	-.507	-10.902
50	.329	-.193	-.011	-.045
52	.439	-.225	.062	.320
53	.248	.226	-.045	-.124
54	.310	-1.003	.024	.191
56	.318	-.733	.012	.048
67	.519	-.469	-.025	-.038
68	.230	.209	.000	-.070
69	.256	.200	.011	-.079
70	2.235	1.393	.000	-10.274
71	.229	.219	-.023	-.113

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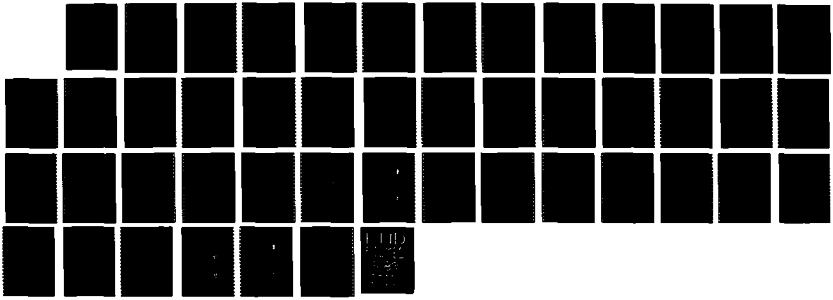

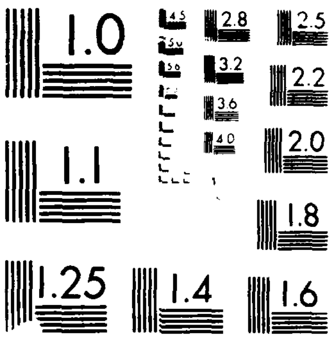
1.0
2.8
2.5
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2.0
1.1
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1.25
1.4
1.6

TABLE D-7. Flaw Response Measurements from Shielded Probes with Probe Lifted Off Surface 0.006 Inch and Perpendicular Orientation (Normalized to Gain=1000, 1-100% Meter Full Scale)

PROBE	SLOT 1	SLOT 2	SLOT 3	SLOT4	CRACK 1	CRACK 2
1	.108	.288	.943	1.778	.474	1.385
2	.094	.299	.935	1.663	.584	1.740
6	.141	.324	1.059	1.969	.732	1.981
7	.161	.405	1.196	1.993	.747	2.119
20	.140	.166	.730	1.086	.590	1.761
21	.120	.093	.575	.795	.613	1.484
27	.134	.299	1.042	2.043	.475	1.505
33	.232	.571	1.806	3.553	1.356	3.773
36	.275	.541	1.955	3.720	1.480	3.843
39	.275	.744	2.532	5.172	1.056	3.679
43	.144	.318	.918	1.675	.712	1.872
57	.147	.339	1.024	1.951	.708	1.979
58	.157	.347	1.078	2.185	.679	1.896
59	.154	.346	1.152	2.182	.672	1.943
62	.174	.535	2.204	4.548	1.148	3.653
63	.248	.523	1.650	3.060	1.151	3.247
64	.162	.285	1.027	1.797	.854	2.297
71	.313	.617	2.650	5.428	1.728	5.827
72	.238	.478	1.514	2.645	1.244	3.281
75	.177	.402	1.208	2.228	.768	2.127
76	.141	.349	1.104	2.062	.760	2.109
77	.189	.283	.809	1.298	.828	2.130
78	.183	.366	1.103	2.012	.757	2.220
79	.133	.280	.923	1.633	.988	2.246
80	.136	.236	.850	1.504	1.387	3.469
81	.219	.458	1.415	2.598	1.080	3.014
82	.175	.364	1.113	2.110	.824	2.286
83	.217	.302	1.004	1.712	1.092	2.806
84	.249	.537	1.805	3.490	1.284	3.530
85	.229	.520	1.705	3.287	1.052	2.912

TABLE D-8. Flaw Response Measurements from Non-shielded Probes with Probe Lifted Off Surface 0.006 Inch and Perpendicular Orientation (Normalized to Gain=1000, 1=100% Meter Full Scale)

PROBE	SLOT 1	SLOT 2	SLOT 3	SLOT4	CRACK 1	CRACK 2
3	.316	.906	3.525	7.853	1.021	3.861
4	.328	.930	3.623	8.099	1.045	3.898
9	.293	.818	3.110	6.677	.942	3.364
11	.318	.919	3.638	8.172	1.137	4.352
15	.339	.952	3.897	8.994	1.151	4.545
18	.314	.902	3.646	8.063	1.215	4.391
22	.275	.726	2.903	6.278	.868	3.375
25	.307	.860	3.230	7.125	.877	3.290
26	.282	.599	2.858	6.302	.881	3.275
28	.263	.788	3.200	6.855	1.087	3.917
29	.320	.913	3.747	8.726	1.066	4.089
32	.294	.856	3.340	7.281	1.063	3.881
38	.344	.927	3.842	8.835	1.121	4.470
40	.344	.957	3.928	9.047	1.032	4.226
41	.334	.934	3.891	9.009	1.116	4.421
42	.291	.814	3.359	7.647	.871	3.278
44	.254	.593	2.682	5.731	.819	2.823
46	.287	.656	2.992	6.558	.799	3.258
48	.438	.647	2.975	6.469	.866	3.284
49	.259	.331	1.934	4.361	.583	2.816
50	.306	.874	3.463	7.654	1.091	3.843
52	.332	.898	3.505	7.746	1.057	3.984
53	.294	.836	3.433	8.108	.983	3.704
54	.294	.784	3.280	7.209	1.146	4.025
56	.290	.840	3.407	7.468	1.087	3.929
67	.325	.845	3.493	7.763	1.153	4.169
68	.298	.878	3.514	8.250	.929	3.622
69	.260	.791	3.275	7.915	.915	3.513
70	.300	.619	2.883	6.424	.755	3.308
71	.301	.832	3.362	7.981	.836	3.287

TABLE D-9. Flaw Response Measurements from Shielded Probes with Probe on Surface and Tilted 10 Degrees from Perpendicular Orientation (Normalized to Gain=1000, 1=100% Meter Full Scale)

PROBE	SLOT 1	SLOT 2	SLOT 3	SLOT4	CRACK 1	CRACK 2
3	.508	1.332	4.763	10.419	1.328	4.722
4	.439	1.225	4.705	10.373	1.229	4.734
9	.253	1.122	4.206	8.940	1.167	4.220
11	.496	1.386	5.515	11.776	1.594	5.750
15	.523	1.555	5.756	12.767	1.659	6.025
18	.505	1.485	5.262	10.791	1.503	5.567
22	.180	.465	2.137	4.819	.736	2.760
25	.331	1.041	3.735	8.058	.972	3.603
26	.001	.339	1.497	3.530	.395	1.864
28	.259	.784	3.233	6.911	1.063	3.917
29	.428	1.237	4.948	11.735	1.282	5.236
32	.497	1.477	5.131	10.792	1.493	5.100
38	.439	1.276	4.879	10.634	1.301	5.232
40	.456	1.264	4.891	11.194	1.227	4.993
41	.214	1.078	4.704	11.231	1.381	5.342
42	.104	.418	1.778	4.289	.453	1.952
44	.113	.339	1.553	3.670	.480	1.891
46	.092	.338	1.772	4.181	.461	1.998
48	.119	.358	1.851	4.359	.538	2.120
49	.001	.001	.850	2.209	.315	1.456
50	.340	1.164	4.427	9.523	1.219	4.516
52	.201	1.136	4.591	10.087	1.267	4.832
53	.320	1.009	3.979	9.265	1.129	4.472
54	.339	1.055	3.826	8.006	1.218	4.479
56	.306	1.166	4.164	8.702	1.242	4.395
67	.478	1.441	5.090	10.741	1.444	5.258
68	.209	.766	3.587	8.881	.905	3.936
69	.313	1.024	4.050	8.369	1.084	4.224
70	.087	.349	1.712	4.150	.552	2.119
71	.316	.994	4.952	9.159	1.276	5.059

TABLE D-10. Flaw Response Measurements from Non-shielded Probes with Probe on Surface and Tilted 10 Degrees from Perpendicular Orientation (Normalized to Gain=1000, 1=100% Meter Full Scale)

PROBE	SLOT 1	SLOT 2	SLOT 3	SLOT4	CRACK 1	CRACK 2
1	.243	.591	1.919	3.418	.847	2.471
2	.120	.649	2.306	3.838	.993	3.052
6	.455	1.280	3.237	4.992	1.439	3.598
7	.533	1.416	3.668	5.751	1.694	4.375
20	.148	.321	.828	1.406	.746	1.978
21	.157	.169	.392	.720	.395	1.106
27	.197	.606	1.911	3.494	.769	2.279
33	.843	2.165	5.330	8.269	2.808	6.608
36	.028	1.044	3.900	6.414	2.059	5.712
39	.105	.294	1.451	3.247	.749	2.674
43	.286	.903	2.405	3.731	1.495	3.413
57	.220	.636	1.930	3.224	1.080	2.683
58	.301	.887	2.589	4.392	1.262	3.279
59	.324	.817	2.541	4.221	1.039	3.238
62	.304	.332	1.376	3.141	.663	2.885
63	.646	1.630	4.275	6.854	2.287	5.733
64	.652	1.720	3.889	5.678	2.206	5.192
71	.339	.520	1.152	2.146	.880	2.597
72	.586	1.532	3.899	6.098	2.536	5.785
75	.305	.771	2.131	3.650	1.217	3.093
76	.672	1.552	4.010	6.208	1.729	4.333
77	.536	1.318	2.943	4.015	2.203	4.573
78	.537	1.451	3.768	5.882	1.946	4.964
79	.698	1.662	3.534	4.989	2.402	5.071
80	.153	.432	1.233	2.084	1.305	2.536
81	.600	1.598	3.942	6.115	2.181	5.284
82	.301	.876	2.424	3.986	1.448	3.482
83	.251	.602	1.482	2.501	1.542	3.561
84	.968	2.541	5.991	9.064	3.017	7.229
85	.500	1.408	3.836	6.318	1.826	4.936

TABLE D-11. Liftoff and Tilt Noise Ratios, and Ratios of Effect of Liftoff and Tilt on Flaw Response for Slot S3, Shielded Probes

PROBE	2 L.O./SLOT	6 L.O./SLOT	TILT/SLOT	SLOT TILT/SLOT	SLOT L.O./SLOT
1	.05	-.01	.10	1.04	.51
2	.04	-.43	.08	.85	.35
6	.09	-.28	.09	1.03	.34
7	.21	.03	.06	.94	.31
20	.18	-.57	-.04	.23	.20
21	.29	-.28	-.35	.11	.16
27	.05	-.08	.02	.96	.53
33	.25	-.05	.14	.72	.24
36	.14	-.30	.11	.60	.30
39	.08	-.14	-.23	.30	.53
43	.17	-.16	.18	.63	.24
57	.08	-.37	.15	.60	.32
58	.10	-.10	.00	.89	.37
59	.12	-.10	.12	.82	.37
62	.06	-.33	-.65	.27	.41
63	.12	-.29	.19	.77	.30
64	.16	-.31	.12	.89	.23
71	.04	-.56	-1.50	.09	.36
72	.11	-.45	.08	.67	.26
75	.21	-.02	.17	.54	.31
76	.18	-.14	.06	1.04	.29
77	.04	-.88	.15	.67	.18
78	.19	-.06	.04	.94	.26
79	.15	-.47	.08	.75	.20
80	.09	-.62	.00	.34	.23
81	.10	-.44	.08	.77	.28
82	.12	-.19	.05	.63	.29
83	.17	-.59	.05	.23	.15
84	.19	-.10	.14	.89	.27
85	.15	-.02	.11	.79	.35

TABLE D-12. Liftoff and Tilt Noise Ratios, and Ratios of Effect of Liftoff and Tilt on Flaw Response for Slot S3, Nonshielded Probes

PROBE	2 L.O./SLOT	6 L.O./SLOT	TILT/SLOT	SLOT TILT/SLOT	SLOT L.O./SLOT
3	.08	.03	.01	.95	.70
4	.06	.00	.01	.93	.72
9	.10	-.07	.08	.88	.65
11	.10	.00	.00	.96	.63
15	.07	-.05	.00	1.00	.68
18	.08	-.14	.01	.89	.62
22	.03	-.23	-.35	.48	.65
25	.06	.00	.01	.86	.74
26	.11	-.40	-3.39	.34	.64
28	.10	-.24	-.08	.58	.57
29	.06	.01	.00	.95	.72
32	.09	-.08	.00	.98	.64
38	.09	-.01	-.01	.84	.66
40	.06	.01	-.01	.93	.75
41	.06	-.02	.00	.87	.72
42	.13	-.12	-2.67	.35	.67
44	.20	-.29	-2.61	.34	.59
46	.12	-.37	-2.56	.39	.66
48	.08	-.51	-2.22	.42	.67
49	.07	-.61	-2.83	.22	.51
50	.07	-.04	-.01	.88	.69
52	.08	-.04	.06	.86	.66
53	.06	.05	-.03	.93	.80
54	.06	-.19	.04	.72	.62
56	.06	-.14	.01	.79	.65
57	.09	-.08	-.01	.90	.62
68	.06	.05	-.02	.80	.78
69	.06	.05	-.02	.96	.78
70	.38	.24	-1.77	.29	.50
71	.05	.05	-.03	1.17	.80

TABLE D-13. Impedance Measurements for Shielded Probes

PROBE	IMPEDANCE @200KHZ (Ohm)	INDUCTANCE (uH)	RESISTANCE (Ohm)	RESONANT FREQ. (KHz)
1	115.526	91.587	10.004	1.339
2	119.493	94.769	9.804	1.319
6	100.602	79.770	8.500	1.429
7	127.887	101.535	8.665	1.259
20	82.948	65.695	8.069	1.509
21	82.757	65.557	7.876	1.509
27	95.106	75.239	10.288	1.419
33	117.362	93.282	5.753	1.289
36	117.166	93.152	5.038	1.299
39	264.689	210.189	17.182	.900
43	126.944	100.734	9.531	1.259
57	91.984	72.900	8.293	1.509
58	106.193	84.174	9.407	1.399
59	106.108	84.126	9.108	1.389
62	222.326	176.609	13.208	.950
63	132.909	105.605	7.330	1.209
64	124.907	99.180	8.274	1.269
71	133.841	106.460	3.957	1.209
72	135.094	107.346	7.335	1.209
75	112.549	89.348	7.812	1.219
76	117.030	92.847	9.113	1.329
77	113.157	89.837	7.727	1.329
78	130.310	103.455	8.898	1.239
79	119.820	95.139	7.964	1.299
80	101.918	80.845	8.129	1.419
81	114.110	90.627	7.157	1.299
82	136.272	108.212	8.867	1.219
83	125.739	99.893	7.268	1.239
84	131.221	104.317	5.890	1.219
85	118.723	94.353	6.078	1.190

TABLE D-14. Impedance Measurements for Nonshielded Probes

PROBE	IMPEDANCE @200KHZ (Ohm)	INDUCTANCE (uH)	RESISTANCE (Ohm)	RESONANT FREQ. (KHz)
3	172.716	137.366	5.789	1.080
4	177.465	141.148	5.742	1.080
9	112.341	89.394	1.066	1.219
11	198.524	157.909	5.976	1.020
15	216.637	172.335	5.645	.940
18	165.039	131.269	5.217	1.090
22	152.721	121.416	6.642	1.130
25	122.026	97.034	4.658	1.259
26	164.447	130.814	4.494	1.030
28	158.952	126.404	5.858	1.130
29	233.165	185.474	6.497	.920
32	155.074	123.322	5.664	1.160
38	224.937	178.929	6.292	.960
40	233.791	185.977	6.343	.940
41	234.270	186.356	6.434	.930
42	166.819	132.726	3.182	.930
44	151.178	120.302	.725	.990
46	134.025	106.619	3.401	1.090
48	132.315	105.261	3.265	1.090
49	196.825	156.449	9.421	.990
50	165.764	131.832	5.742	1.110
52	171.336	136.266	5.822	1.070
53	195.580	155.576	5.539	1.030
54	158.164	125.781	5.719	1.170
56	159.414	126.778	5.635	1.170
67	167.483	133.208	5.455	1.120
68	192.957	153.490	5.433	1.030
69	205.654	163.583	6.081	.970
70	152.975	121.727	1.558	.980
71	187.332	149.015	5.256	1.150

TABLE D-15. MIL STD XXX Measurements for Shielded Probes

PROBE	AL.-TO-TI. IMPEDANCE CHANGE (OHMS)
1	4.551
2	8.869
6	7.146
7	6.989
20	10.840
21	10.024
27	7.472
33	7.562
36	7.449
39	21.323
43	7.091
57	8.383
58	7.309
59	7.292
62	23.707
63	8.923
64	8.743
71	11.170
72	8.839
75	4.759
76	9.126
77	8.857
78	7.800
79	8.190
80	8.509
81	9.180
82	7.492
83	9.393
84	6.889
85	5.516

TABLE D-16. MIL STD XXX Measurements for Nonshielded Probes

PROBE	AL.-TO-TI. IMPEDANCE CHANGE (OHMS)
3	15.821
4	16.456
9	12.432
11	19.531
15	21.001
18	20.037
22	20.136
25	10.425
26	33.293
28	23.339
29	19.282
32	18.102
38	22.390
40	20.320
41	21.754
42	31.645
44	32.244
46	24.466
48	25.292
49	34.800
50	16.444
52	18.715
53	12.897
54	18.747
56	17.729
67	19.165
68	13.409
69	14.204
70	30.838
71	12.043

APPENDIX E

PROPOSED MILITARY SPECIFICATION MIL-P-ABC,
"PROBES, EDDY CURRENT, ABSOLUTE, FLAW DETECTION"

APPENDIX E

PROPOSED MILITARY SPECIFICATION MIL-P-ABC,
"PROBES, EDDY CURRENT, ABSOLUTE, FLAW DETECTION"

1. SCOPE

1.1 Scope. This specification establishes the minimum performance, test, and acceptance requirements for single coil, absolute, surface inspection, eddy current probes (shielded or nonshielded) to be used with flaw detection instruments equivalent to the Hocking UH-B. The specification applies only to probes with coil diameters 0.5 inch or less and having a nominal operating frequency of 200 kHz. This specification also establishes a standard nomenclature for the salient features of applicable probes, and a standard probe numbering system that codifies the basic characteristics of the probes.

1.2 Classification. The probes covered by this specification shall be classified according to electromagnetic type and body style.

1.2.1 Type. The types of probes shall be as follows:

Type S - Shielded (see Figures 1 and 2).

Type N - Nonshielded (see Figures 1 and 2).

1.2.2 Style. The styles of probes shall be as follows:

Style F - Flat tip (see Figure 1).

Style R - Rounded tip (see Figure 2).

2. APPLICABLE DOCUMENTS

2.1 Government documents.

2.1.1 Specifications, standards, and handbooks.

None.

2.1.2 Other government documents. The following government documents of issue in effect on the date of solicitation shall form a part of this specification to the extent specified herein.

DEPARTMENT OF DEFENSE

TECHNICAL ORDERS

TO 33B2-7-11 Flaw Detector, Eddy Current, Operation and Maintenance Instructions with Parts List

2.2 Other publications. The following publications of issue in effect on the date of the solicitation form a part of this specification to the extent specified herein.

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

ASTM E 268 Standard Definitions of Terms Relating to Electromagnetic Testing

G & C MERRIAM COMPANY

Webster's New International Dictionary

2.3 Order of precedence. In the event of a conflict between the text of this specification and the references cited herein, the text of this specification shall take precedence.

2.4 Abbreviations, symbols, and definitions. Abbreviations, symbols, and definitions used herein are defined in this document, in ASTM E 268, or in Webster's New International *Dictionary*. In the event of conflict between defining documents, the precedence of document authority shall be in the order named.

3. REQUIREMENTS

3.1 Item definition. The items covered by this specification are single coil, absolute, surface inspection, eddy current probes which are used for detection of anomalies in materials having the same range of conductivity as aluminum and aluminum alloys [approximately 25 to 65% of the International Annealed Copper Standard (IACS)]. The probes have a nominal operating frequency of 200 kHz, a maximum coil diameter of 0.5 inch, and are intended for use with meter type instruments equivalent to the Hocking UH-B. The probes are classified into two electromagnetic types-shielded and nonshielded, and

into two body styles - flat tip, and rounded tip. These and other salient features of the probes are illustrated in Figures 1 and 2.

3.1.1 Standard probe nomenclature. The nomenclature used in Figures 1 and 2 is established as the standard for probes covered by this specification.

3.2 Characteristics.

3.2.1 Electrical characteristics.

3.2.1.1 Nominal frequency. The nominal frequency shall be 200 kHz. For purposes of this specification, the nominal frequency is defined as the target value of the operating frequency. For probes used with instruments such as the Hocking UH-B, the actual operating frequency is determined in part by the probe inductance.

3.2.1.2 Impedance.

3.2.1.2.1 Inductance. The probe inductance shall be in the range from 110 to 165 μH.

3.2.1.2.2 Resistance. The probe resistance shall be in the range from 2 to 7 ohms.

3.2.2 Performance characteristics.

3.2.2.1 Flaw response. The minimum acceptable flaw response is 100% of full scale deflection of the eddy current instrument meter at a gain of less than or equal to 750. The flaw response is defined as the maximum meter deflection obtained by starting from a zero reading with the probe in an unflawed area of the 7075-T6 aluminum test block, away from edges, and scanning the probe over a 0.020 inch deep slot.

3.2.2.2 Test gain. The test gain is the gain setting which gives a 100% meter deflection from a 0.020 inch deep slot in the test block.

3.2.2.3 Liftoff response. The maximum acceptable liftoff response must be within +25% to -10% full scale deflection of the eddy current instrument meter at the test gain setting. The liftoff response is defined as the change in meter deflection obtained by starting from a zero reading with the probe in an unflawed area of the test block, away from edges, and lifting the probe off of the block surface by 0.002 inch with probe coil axis at 90 degrees to test block surface throughout test.

3.2.2.4 Tilt response. The tilt response must be within +25% to -10% of full scale deflection of the eddy current instrument meter at the test gain setting. The tilt response is defined as the change in meter deflection obtained by starting from a zero reading with the probe in an unflawed area of the test block, away from edges, with the probe coil axis 90 degrees to the test block surface and then changing the orientation to 80 degrees. This

requirement does not apply to flat tip probes with a tip diameter greater than 0.25 inch.

3.2.2.5 Liftoff flaw response. The minimum acceptable liftoff flaw response is 20% of full scale deflection of the eddy current instrument meter at the test gain setting. The liftoff flaw response is defined as the maximum meter deflection obtained by starting with a zero reading with the probe on an unflawed area of the test block, away from edges, and with a 0.006 inch thick plastic shim between the probe and the test block, and scanning the probe over the 0.020 inch deep slot with probe coil axis at 90° to test block surface throughout test.

3.2.2.6 Tilt flaw response. The minimum acceptable tilt flaw response is 20% of full scale deflection of the eddy current instrument meter at the test gain setting. The tilt flaw response is defined as the maximum meter deflection obtained by starting with a zero reading with the probe on an unflawed area of the test block, away from edges, and with the probe coil axis oriented at 80 degrees to the test block surface, and scanning the probe over the 0.020 inch deep slot. This requirement does not apply to flat tip probes with a tip diameter greater than 0.25 inch.

3.2.2.7 Flaw response width. This requirement applies to shielded probes only. The maximum flaw response width is 100% of the coil diameter. The flaw response width is defined as the distance traveled by the probe between the points at which the meter deflection is 50% of maximum as the probe is scanned over the 0.020 inch deep slot in the test block.

3.3 Design and construction. The probe shall be designed and constructed in a manner that includes intrinsic ruggedness so as to ensure reliable and consistent performance under the severe operational hazards encountered in the workplace.

3.3.1 Wearface material. The end of the coil at the face of the probe shall be covered with a wear resistant material (e.g. alumina-filled epoxy)of sufficient thickness to provide a durable surface which will protect the coil from mechanical damage under normal probe usage.

3.3.2 Stress relief. The cable attachments at the probe and at the connector shall be designed and fabricated in a manner that will mitigate against failure because of excessive pull stress or repeated bending at sharp angles. As a minimum, the following requirements shall be met.

3.3.2.1 Pull stress. The cable shall be secured within the probe so that when tested as specified in 4.2.1.1 there is no perceptible variation in the d.c. electrical resistance of the circuit through the cable and probe and there is no perceptible linear motion of the cable relative to the probe.

3.3.2.2 Bending stress. The cable shall exit the probe through an attached boot of resilient material (e.g., rubber) or coiled spring designed to relieve the bending stress at the probe. The boot shall have a length of at least 8 cable diameters. When tested as specified in 4.2.1.2, the radius of curvature of the inner arc of the boot and cable shall nowhere be less than 5 cable diameters.

3.3.3 Nameplates and product marking.

3.3.3.1 Information. Each probe shall be permanently marked with the following information as a minimum.

a. Nominal operating frequency (in kHz)

b. Probe type (S-shielded, N-nonshielded)

c. Coil diameter

d. Tip diameter

e. Probe style (F-flat tip, R-rounded tip)

The above items shall be incorporated into a single descriptor as shown below:

200 - BBB - CCC - X-Y

where:

200 is the nominal frequency in kHz

BBB is the coil diameter in inches

CCC is the tip diameter in inches

X is the probe type (S - shielded, N - non shielded)

Y is the probe style (F - flat tip, R - rounded tip).

Example: 200 - .375 - .5 - S-F designates a 200 kHz shielded probe with a coil diameter of 0.375 inches and a flat tip of 0.5 inch diameter.

In addition, the following information shall also be marked on the probe:

d. Manufacturer's name

e. A manufacturer's model number which is sufficient for obtaining a complete description of the probe configuration through contact with the manufacturer or from the manufacturer's catalog.

f. Serial number

3.3.3.2 Marking methods.

3.3.3.2.1 Direct marking. Markings applied directly to the probe shall be affixed only by die stamping, etching, or engraving.

3.3.3.2.2 Information plates. An information plate used for marking a probe with the specified information shall be fastened in such a manner as

to remain firmly affixed throughout the normal life expectancy of the probe and in such a location that it will not impair or restrict the intended use of the probe.

3.3.4 Workmanship.

3.3.4.1 General. The probe shall be free from burrs, sharp edges, and any other damage or defect that could make the probe unsatisfactory for its intended use.

3.3.4.2 Cleaning. After fabrication, the probe shall be cleaned of smudges and any other foreign material which might detract from its appearance or intended function. The cleaning process shall have no deleterious effect on the probe.

3.3.4.3 Threaded parts or devices. Threaded parts or devices shall show no evidence of cross threading, mutilation, or detrimental or hazardous burrs.

3.3.4.4 Flat tip probes. The face of a flat tip probe shall be flat and free of extraneous material which would prevent the face of the probe from resting flat on the surface to be inspected.

3.3.4.5 Rounded tip probes. The face of a rounded tip probe shall have a smooth, uniform curvature and be free of extraneous material which would impair the uniformity of curvature.

4. QUALITY ASSURANCE PROVISIONS

4.1 General. The supplier shall bear full responsibility for the quality conformance of the probes delivered.

4.1.1 Responsibility for inspections. The supplier shall be responsible for performing all of the inspections that are necessary to assure compliance with all performance requirements. The inspections specified herein for each performance requirement shall be used to determine compliance. The purchaser reserves the right to witness or to separately perform any or all specified tests and verifications.

4.2 Quality conformance inspections. All requirements set forth in Section 3 shall be verified by the tests and examinations described in the appropriate paragraphs of Section 4.2.

4.2.1 Visual and mechanical inspections. Inspections for requirements of Section 3.3 shall be performed using the procedures and inspection aids commonly used in quality control laboratories of machine shops.

4.2.1.1 Cable pull stress. The cable pull stress test is accomplished by firmly holding the probe in a fixture that does not damage its surface while applying an axial load to the end of the cable. The load shall be increased gradually from zero to 12.5 pounds over a time span of 20 seconds. The electrical resistance of the cable and probe, as measured at the end of the cable shall be monitored continuously during the application of the

load using a laboratory ohmmeter capable of measuring resistance changes of 1 percent or less. Compliance with 3.3.2.1 will be indicated by these results:

a. the electrical resistance does not vary by more than 1 percent;

b. the linear motion of the cable relative to the probe does not exceed 0.02 inch.

4.2.1.2 Cable bend stress. The cable bend stress test shall be accomplished with the probe held securely in a position such that the center-line of the exit hole is horizontal. The free end of the cable shall be loaded with a one-quarter pound weight. Compliance with 3.3.2.2 will be indicated by these results:

a. the length of the boot measured from the probe-boot interface to the end of the boot is as specified;

b. by sight inspection, the inner arc of the boot and cable is smooth and uniform;

c. by sight comparison, the inner arc of the boot and cable everywhere falls outside the arc of a circle of the specified radius with a point of tangency at the probe-boot interface.

4.2.2 Nominal frequency. Nominal frequency is not a measurable characteristic. It is specified as a reference value only (see 3.2.1.1).

4.2.3 Probe impedance

4.2.3.1 Probe inductance. Conformance to the probe inductance requirements specified in 3.2.1.2.1 shall be verified by measurement with a commercially available, high quality impedance measuring instrument capable of ±8 percent accuracy. If the probe does not have a permanently attached cable, the measurement should be made by connecting the probe to the instrument with a RG 174/U coaxial cable having a nominal length of 5 ft. with suitable connectors. The inductance measurement shall be performed with the probe positioned in air and well away from any metal. Record the inductance measurement on the data sheet (Figure 3).

4.2.3.2 Resistance. Conformance to the probe resistance requirements specified in 3.2.1.2.2 shall be verified by measurement with a commercially available, high-quality impedance measuring instrument capable of ±5% accuracy and capable of resolving 0.5-ohm resistance. Requirements for the probe cable are the same as specified in 4.2.3.1. Record the resistance measurement on the data sheet (Figure 3).

4.2.4 Performance test procedure. This procedure describes all of the tests required to verify that the probe under test conforms to the performance requirements of 3.2.2.

4.2.4.1 Test equipment. The following items of test equipment are required to conduct the tests specified in this procedure.

(a) Hocking UH-B eddy current instrument (or equivalent) which has been calibrated according to factory specifications using a Hocking electronic reference box, type b (or equivalent). Calibration must have been performed no longer than 6 months prior to the eddy current probe test.

(b) Test block-Air Force general purpose eddy current standard, NSN 6635-01-092-5129, P/N 7947479-10.

(c) Positioning mechanism capable of holding the probe so that the axis of the coil can be positioned at 90 degrees and at 80 degrees with respect to the test block surface. The fixture shall be capable of holding the probe against the test block surface under light spring load and maintaining the angular alignment with the test block surface when the probe is lifted off of the surface by placing a 0.006 inch plastic shim between the probe tip and block surface. The positioning mechanism shall also be capable of scanning the probe over the test block surface in either the 80 or 90 degree orientation and measuring the probe position in the direction parallel with the test block surface with an accuracy of 0.004 inch. A schematic diagram of a suggested positioning fixture is shown in Figure 4.

(d) 0.006- and 0.002-inch thick plastic shims.

4.2.4.2 Test conditions.

4.2.4.2.1 Environmental conditions. The tests described in this procedure shall be conducted under laboratory conditions. Normal ambient conditions of temperature and relative humidity will provide an adequate environment; however, the following environmental limits must be observed:

(a) Temperature: 50 to 90 degrees F (10 to 32 degrees C)

(b) Humidity: <85% relative

(c) Altitude: <15,000 feet

4.2.4.2.2 Test configuration. Probes having permanently attached cables shall be connected directly to the test instrument with the cable. Probes without a permanently attached cable shall be connected to the test instrument with an RG 174/U coaxial cable having a nominal length of 5 feet and suitable connectors.

4.2.4.3 Test procedure.

(a) Record date, operator and probe identification information on data sheet (Figure 3).

(b) Set the Hocking UH-B instrument controls as follows:

Metal - Al Mg

Zero/Sort - fully counterclockwise

Alarm - audio off

Mode - normal

Frequency - 200 kHz

Alarm Level - 100

Gain - 100

Power - on

(c) Flaw response and test gain measurement. Connect the probe under test to the instrument. Place the probe in the positioning fixture with the probe coil axis at a 90 degree angle to the test block surface in an area midway between the 0.010 and 0.020 inch deep slots and at least 0.5 inch away from any edge. This will be the probe starting position. Train the instrument for liftoff using a 0.006 inch thick plastic shim according to the instructions in TO 33132-7-4, page 5-2. Zero the meter. Using the positioning fixture, slowly scan the probe over the 0.020 inch deep slot in the test block and observe the maximum meter deflection. Adjust the instrument gain to obtain a maximum meter deflection of 100% when the probe is scanned over the 0.020 inch deep slot. The instrument shall be rezeroed with the probe at the

starting position after any change in gain. The flaw response requirements in 3.2.2.1 must be met. Record the test gain setting on the data sheet (see 3.2.2.2).

(d) Liftoff response. Move the probe to the starting position. Train the instrument for liftoff using the 0.006 inch thick plastic shim. Zero the instrument. With the probe resting on the test block surface, insert the 0.002-inch thick plastic shim between the probe and test block and record the maximum meter deflection (+ or -) on the data sheet. The liftoff response must meet the requirements in 3.2.2.3.

(e) Tilt response. This step does not apply to flat tip probes with tip diameter greater than 0.25 inch. Tilt the probe from 90 degrees with respect to the specimen surface to 80 degrees with respect to the specimen surface. Record the maximum meter deflection (+ or -) on the data sheet. The tilt response must meet the requirements in 3.2.2.4.

(f) Tilt flaw response. This step does not apply to flat tip probes with tip diameter greater than 0.25 inch. With the probe at 80 degrees from the previous step, zero the instrument. Scan the probe over the 0.020 inch deep slot and record the maximum meter deflec-

tion on the data sheet. The tilt flaw response must meet the requirements in 3.2.2.6.

(g) Liftoff flaw response. Return the probe to the 90 degree position and the starting position on the test block. Place a 0.006 inch thick plastic shim between the probe and the test block surface. The shim shall be large enough to extend from the start position to 0.75 inch on the opposite side of the 0.020 inch deep slot. Zero the instrument. Scan the probe over the 0.020 inch deep slot (with the shim between the probe and test block and record the maximum meter deflection on the data sheet. The liftoff flaw response must meet the requirements in 3.2.2.5.

(h) Flaw response width. This step applies to shielded probes only. Return the probe to the start position and remove the shim. Zero the instrument. Scan the probe to the position where a 50% meter indication is obtained. Note this position on the scale of the positioning fixture. Scan the probe over the 0.020 inch deep slot until the meter indication peaks and then decreases to a 50% indication. Record the distance the probe was scanned between the two 50% indication locations on the data sheet. The flaw response width must meet the requirements in 3.2.2.7.

5. PACKAGING

This section is not applicable.

6. NOTES

6.1 Intended use. The probes covered by this specification are to be used for the detection of flaws in or near the exterior surfaces of aluminum parts and structures, etc.

6.2 Ordering data. Acquisition documents should specify the following as a minimum:

a. Title, number, and date of this specification.

b. Nominal operating frequency

c. Probe type (shielded or nonshielded)

d. Coil diameter

e. Configuration of probe body (including style), cable and connector, either by description or by manufacturer's model number.

f. Type of quality certification that is needed. Example: "The contractor shall certify in writing that each probe delivered

meets all the applicable requirements set forth in the purchase specification."

g. A requirement for the supplier to warrant the conformance of the probes delivered. Example: "The contractor shall warrant that the probes will conform to all performance requirements for a period of 90 days from the date of acceptance by the purchaser."

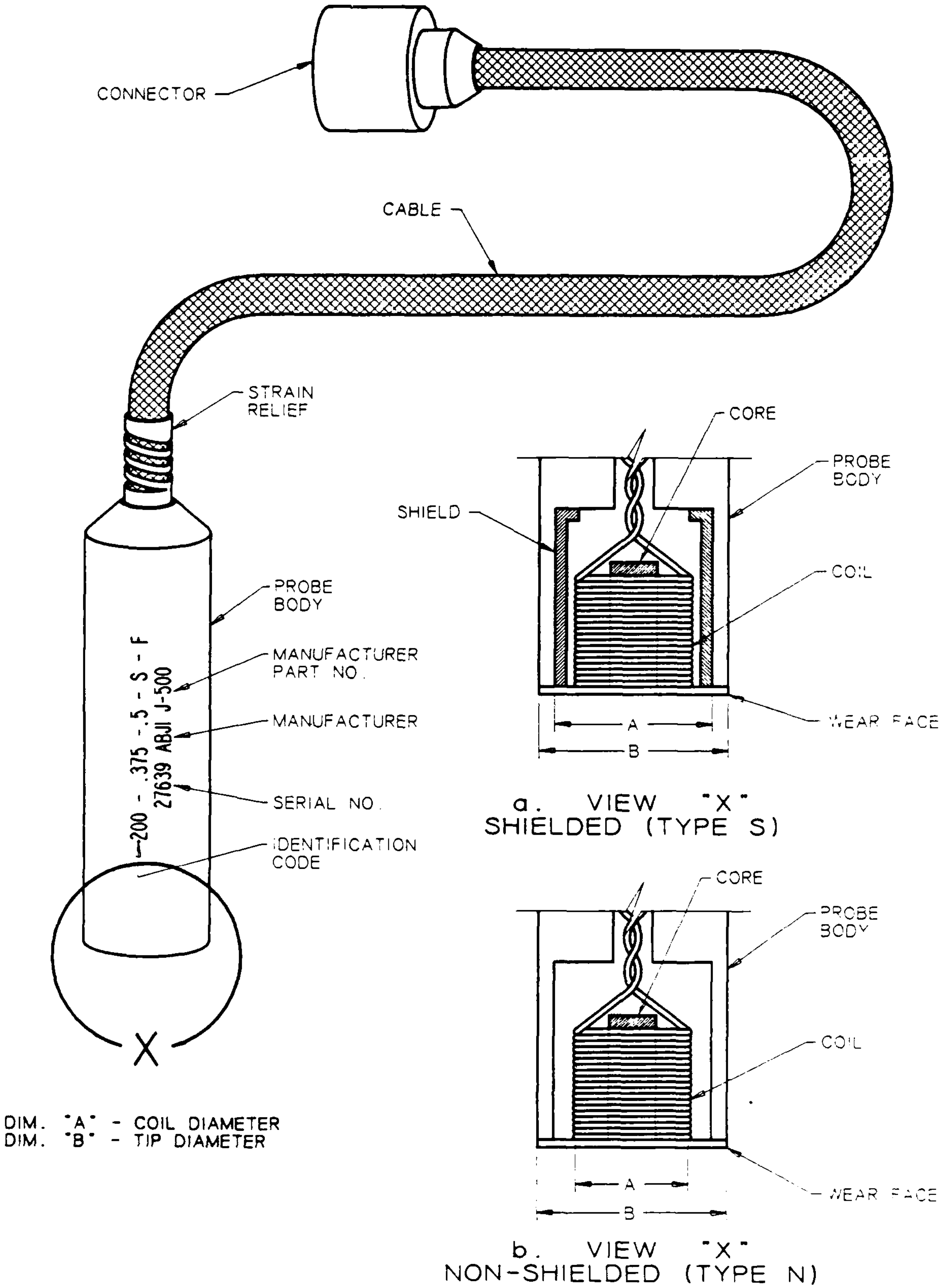

Figure 1. Typical flat tip (style F) probe and standard nomenclature

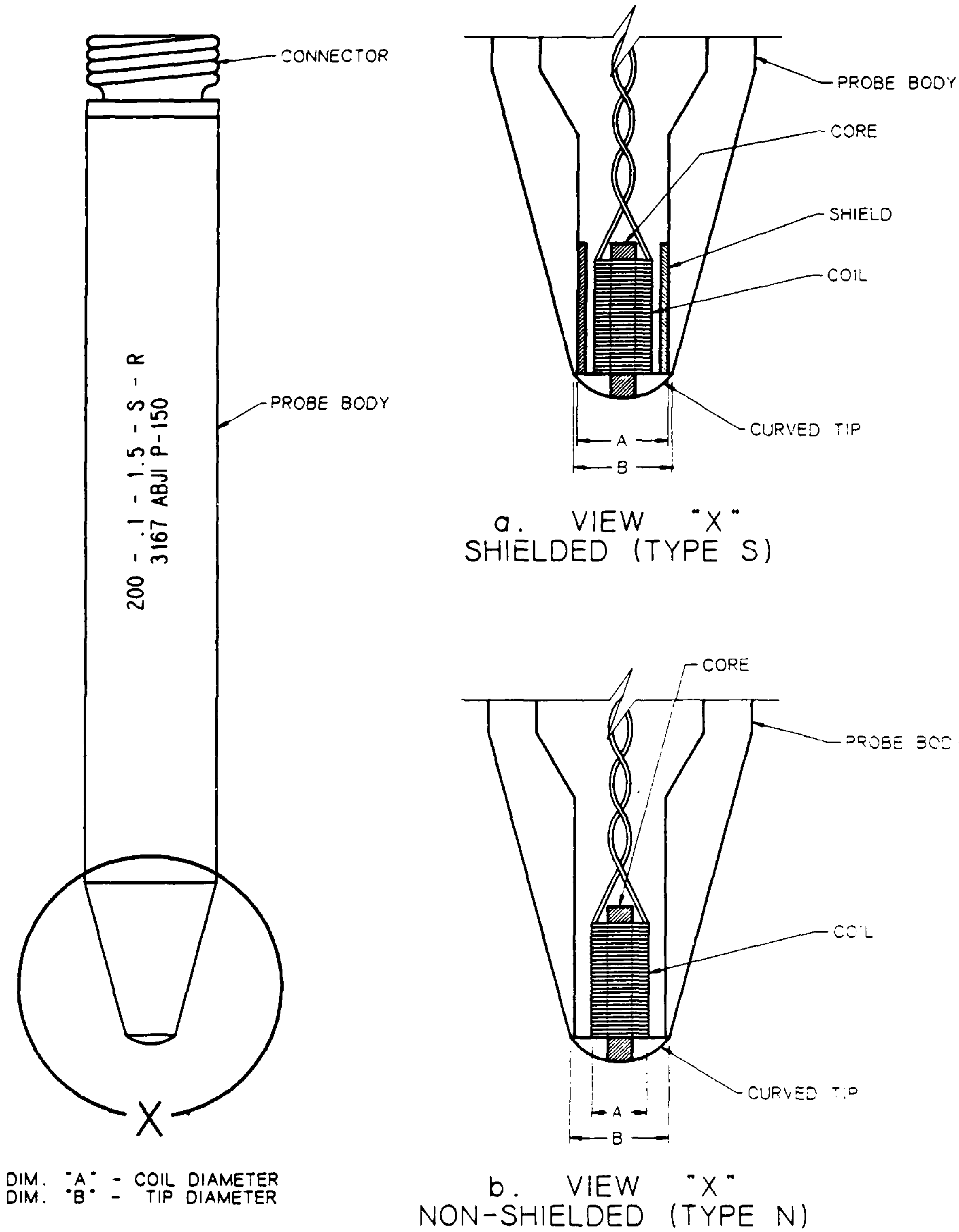

Figure 2. Typical rounded tip (style R) pencil probe and standard nomenclature

EDDY CURRENT PROBE DATA SHEET

Date:______________________ Operator:__________________

Probe Identification

Probe descriptor no.__________ Serial No. ______________

Manufacturer ________________ Manufacturer Part No. ___________

Nominal Frequency ___________ Type _________________________

Coil Diameter _______________ Tip Diameter __________________

Other Descriptive Information

Measured Parameters

Inductance __________________

Resistance __________________

Test Gain (for 100% Response to 0.02 inch deep slot) ___________________

Liftoff Response (% of full scale) _________________________

Tilt Response (% of full scale) ______________________

Liftoff Flaw Response (% of full scale) _____________________

Tilt Flaw Response (% of full scale) ____________________

Flaw Response Width (inches) _____________________

Figure 3. Example of eddy current probe data sheet

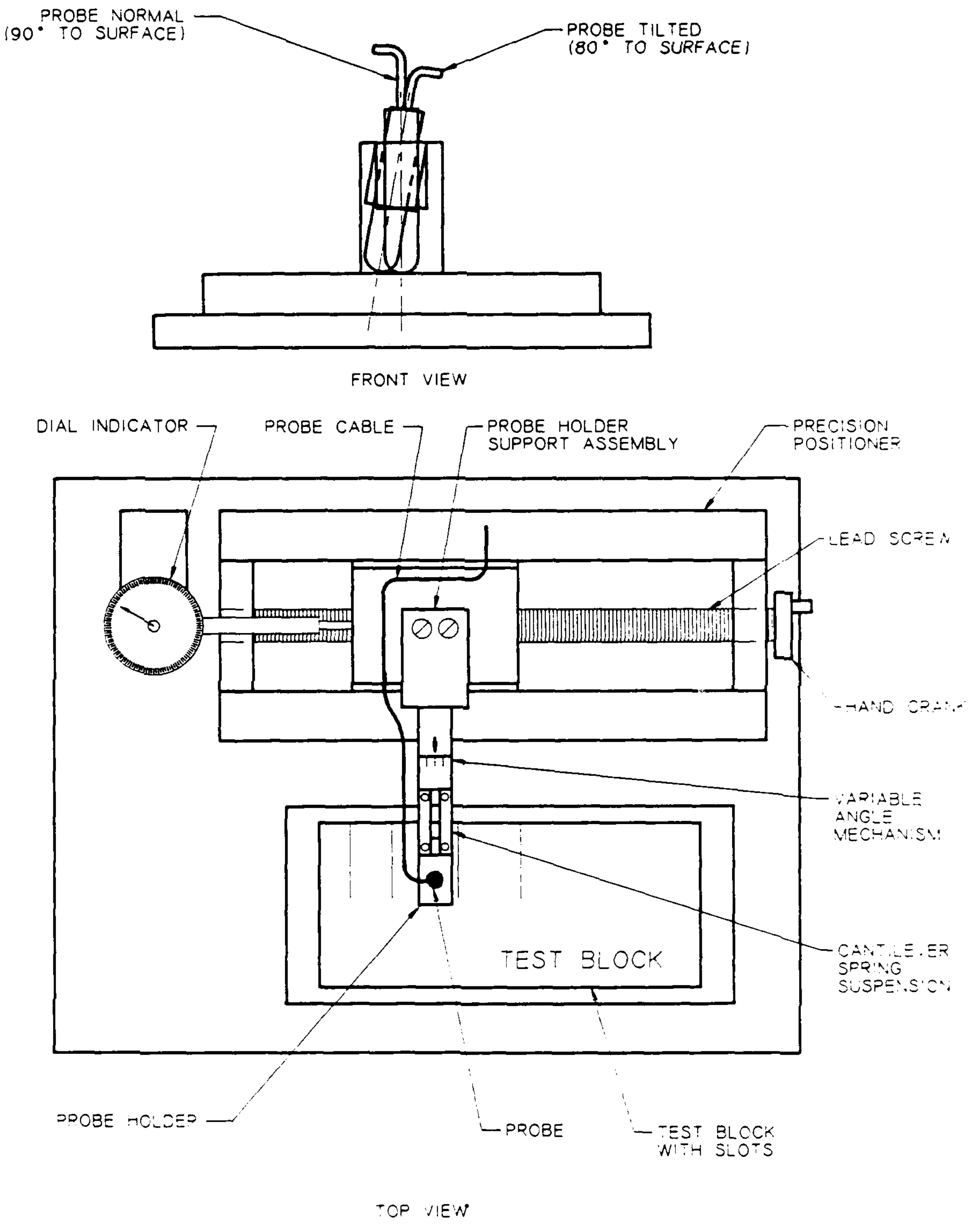

Figure 4. Probe positioning mechanism for performance test

APPENDIX F

EDDY CURRENT PROBE FIELD TEST PROCEDURE

APPENDIX F

EDDY CURRENT PROBE FIELD TEST PROCEDURE

1. SCOPE

1.1 Scope. This specification establishes a simplified field performance test procedure for single coil, absolute, surface inspection, eddy current probes (shielded or nonshielded) to be used with flaw detection instruments equivalent to the Hocking UH-B. The specification applies only to probes with coil diameters 0.5 inch or less and having a nominal operating frequency of 200 kHz.

2. APPLICABLE DOCUMENTS

2.1 Government documents.

2.1.1 Specifications, standards, and handbooks.

None.

2.1.2 Other government documents. The following government documents of issue in effect on the date of solicitation shall form a part of this specification to the extent specified herein.

DEPARTMENT OF DEFENSE

TECHNICAL ORDERS

TO 33B2-7-11Flaw Detector, Eddy Current, Operation and Maintenance Instructions with Parts List

3. REQUIREMENTS

3.1 Item definition. The items covered by this test procedure are single coil, absolute, surface inspection, eddy current probes which are used for detection of anomalies in materials having the same range of conductivity as aluminum and aluminum alloys [approximately 25 to 65% of the International Annealed Copper Standard (IACS)]. The probes have a nominal operating frequency of 200 kHz, a maximum coil diameter of 0.5 inch, and are intended for use with meter type instruments equivalent to the Hocking UH-B. The probes are classified into two electromagnetic types-shielded and nonshielded, and into two body styles - flat tip, and rounded tip. These and other salient features of the probes are illustrated in Figures 1 and 2.

3.2 Performance Characteristics.

3.2.1 Flaw response. The minimum acceptable flaw response is 100% of full scale deflection of the eddy current instrument meter at a gain of less than or equal to 750. The flaw response is defined as the maximum meter deflection obtained by starting from a zero reading with the probe in an unflawed area of the 7075-T6 aluminum test block, away from edges, and scanning the probe over a 0.020 inch deep slot.

3.2.2 Test gain. The test gain is the gain setting which gives a 100% meter deflection from a 0.020 inch deep slot in the test block.

3.2.3 Liftoff response. The liftoff response must be within +25% to -10% full scale deflection of the eddy current instrument meter at the

test gain setting. The liftoff response is defined as the change in meter deflection obtained by starting from a zero reading with the probe in an unflawed area of the test block, away from edges, and lifting the probe off of the block surface by 0.002 inch with probe coil axis at 90 degrees to test block surface throughout test.

3.2.4 Liftoff flaw response. The minimum acceptable liftoff flaw response is 20% of full scale deflection of the eddy current instrument meter at the test gain setting. The liftoff flaw response is defined as the maximum meter deflection obtained by starting with a zero reading with the probe on an unflawed area of the test block, away from edges, and with a 0.006 inch thick plastic shim between the probe and the test block, and scanning the probe over the 0.020 inch deep slot with probe coil axis at 90° to the test block surface throughout test.

4. QUALITY ASSURANCE PROVISIONS

4.1 Performance test procedure. This procedure describes all of the tests required to verify that the probe under test conforms to the performance requirements of 3.2.

4.1.1 Test equipment. The following items of test equipment are required to conduct the tests specified in this procedure.

(a) Hocking UH-B eddy current instrument (or equivalent) which has been calibrated according to factory specifications using a Hocking electronic reference box,

type b (or equivalent). Calibration must have been performed no longer than 6 months prior to the eddy current probe test.

(b) Test block-Air Force general purpose eddy current standard, NSN 6635-01-092-5129, P/N 7947479-10.

(c) 0.006- and 0.002-inch thick plastic shims.

4.1.2 Test conditions.

4.1.2.1 Environmental conditions. The tests described in this procedure shall be conducted under laboratory conditions. Normal ambient conditions of temperature and relative humidity will provide an adequate environment; however, the following environmental limits must be observed:

(a) Temperature: 50 to 90 degrees F (10 to 32 degrees C)

(b) Humidity: <85% relative

(c) Altitude: <15,000 feet

4.1.2.2 Test configuration. Probes having permanently attached cables shall be connected directly to the test instrument with the cable. Probes without a permanently attached cable shall be connected to the test instrument with an RG 174/U coaxial cable having a nominal length of 5 feet and suitable connectors.

4.1.3 Test procedure.

(a) Record date, operator and probe identification information on data sheet (Figure 3).

(b) Set the Hocking UH-B instrument controls as follows:

Metal - Al Mg

Zero/Sort - fully counterclockwise

Alarm - audio off

Mode - normal

Frequency - 200 kHz

Alarm Level - 100

Gain - 100

Power - on

(c) Flaw response and test gain measurement. Connect the probe under test to the instrument. Hold the probe with the probe coil axis at a 90 degree angle to the test block surface in an area midway between the 0.010 and 0.020 inch deep slots and 0.5 inch away from the edge. (The use of a simple fixture such as a nonmetallic block placed next to the probe will aid in maintaining the 90° angle.) This will be the probe starting position. Train the instrument for liftoff using a 0.006 inch thick plastic shim according to the instructions in TO 33132-7-4, page 5-2.

Zero the meter. Slowly scan the probe over the 0.020 inch deep slot in the test block and record the maximum meter deflection. Adjust the instrument gain to obtain a maximum meter deflection of 100% when the probe is scanned over the 0.020 inch deep slot. The instrument shall be rezeroed with the probe in the starting position after any change in gain. The flaw response requirements in 3.2.1 must be met. Record the test gain setting on the data sheet (see 3.2.2).

(d) Liftoff response. Move the probe to the starting position. Train the instrument for liftoff using the 0.006 inch thick plastic shim. Zero the instrument. With the probe resting on the test block surface, and at a 90° angle to the surface, insert the 0.002-inch thick plastic shim between the probe and test block and record the maximum meter deflection (+ or -) on the data sheet. The liftoff response must meet the requirements in 3.2.3.

(e) Liftoff flaw response. Return the probe to the starting position on the test block. Place a 0.006 inch thick plastic shim between the probe and the test block surface. The shim shall be large enough to extend from the start position to 0.75 inch on the opposite side of the 0.020 inch deep slot. Zero the instrument. With the probe 90° to the test block

surface, scan the probe over the 0.020 inch deep slot (with the shim between the probe and test block) and record the maximum meter deflection on the data sheet. The liftoff flaw response must meet the requirements in 3.2.4.

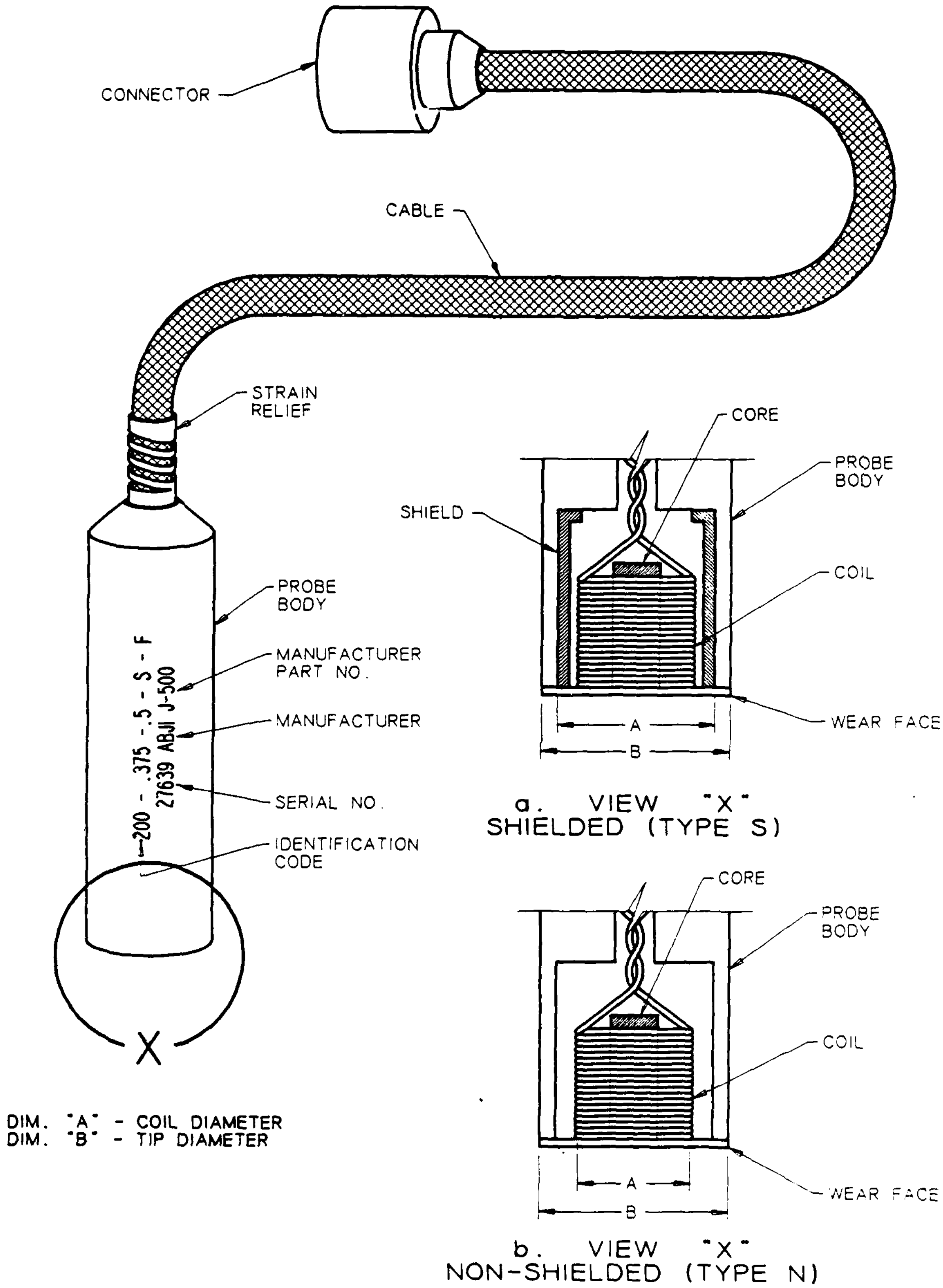

Figure 1. Typical flat tip (style F) probe and standard nomenclature

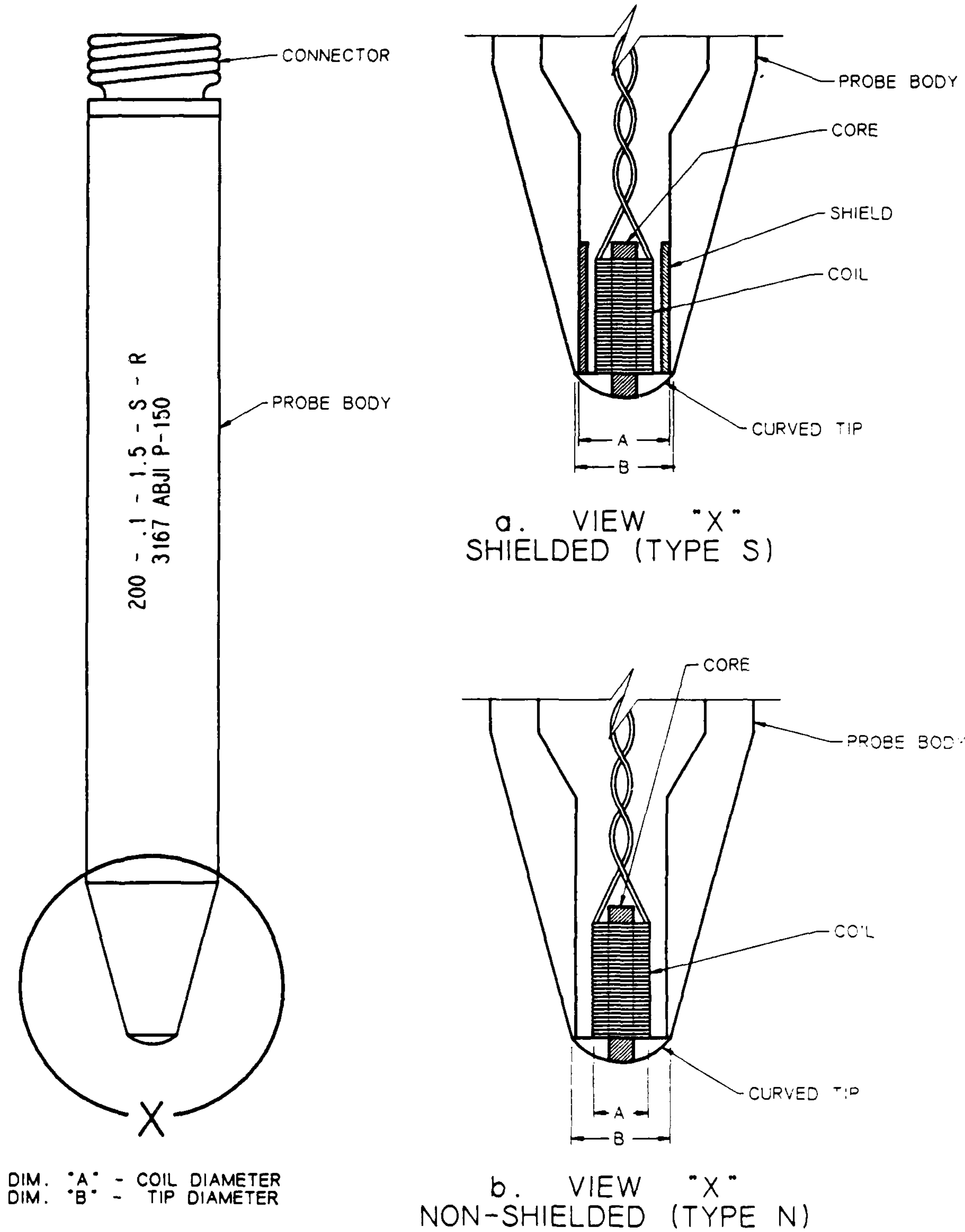

Figure 2. Typical rounded tip (style R) pencil probe and standard nomenclature

EDDY CURRENT PROBE DATA SHEET
FOR FIELD TEST PROCEDURE

Date:______________________________ Operator:_________________________

Probe Identification

Probe descriptor no.______________ Serial No. ____________________

Manufacturer ______________________ Manufacturer Part No. _______________

Other Descriptive Information

Measured Parameters

Test Gain (for 100% Response to 0.02 inch deep slot) ___________________________

Liftoff Response (% of full scale) ___________________________________

Liftoff Flaw Response (% of full scale) _____________________________

Figure 3. Example of eddy current probe data sheet for field test procedure